AFIT/GLM/LAL/99M-1

MAINTENANCE RESOURCES EVALUATION TECHNIQUE

THESIS

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Presented to the Faculty of the Graduate School of Logistics

and Acquisition Management of the Air Force Institute of Technology

Air University

Air Education and Training Command

In Partial Fulfillment of the Requirements for the

Degree of Master of Science in Logistics Management

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March 1999

Acknowledgements

I would like to express my sincere gratitude to my faculty support team: Major Stephen Swartz, my thesis advisor, who provided the right questions at the right time encouraging the quest for the adequate balance between research scope and results validity, and Major Alan Johnson, my thesis reader, whose insights in mathematical modeling and simulation were key factors for the materialization of this project. In addition, the thoroughness and patience of both advisor and reader have substantially improved the quality of this document.

I would also like to thank the Argentine Air Force officers who have spent their valuable time providing their professional expertise in the logistics field: *Comodoro* Fernado Rico, *Comodoro* Alfredo E. Longo, *Vicecomodoro* Jorge Discoli, *Vicecomodoro* José R. Lombardi, *Mayor* Guillermo H. Santilli, and *Mayor* Carlos A. Filgueiras.

Most specially and from the bottom of my heart, I would like to thank my wife Roxana and my children Gino, Romina, Cecilia and Franco, whose understanding and patience provided the necessary support during all this long project.

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Abstract

The Argentine Air Force (AAF) has undertaken the task of reviewing its logistics doctrine with the aim of supporting its mission on the basis of better-designed resource structures. The adequate sizing of logistics support is essential to obtain the desired military capability, while optimizing resource use. A decision support tool tailored to the AAF environment is needed to size that logistics support. This research developed a mathematical logistics model to evaluate the mean number of aircraft that can be restored in a given time interval between consecutive sorties, for a given maintenance resources mix and base physical geometry. This *maintenance resources evaluation technique* (MRET) uses an analytical methodology to estimate the expected parameters of the unscheduled down time distribution. These parameters are then used in a Monte Carlo simulation of the user-defined network of scheduled and unscheduled maintenance tasks necessary to launch aircraft sorties. The MRET, although not externally validated, performed successfully during the verification process conducted in this research. Programmed on a spreadsheet, the MRET combines a high response speed with a moderately detailed description of the operations and logistics scenario. These characteristics make the model suitable for the AAF environment.

MAINTENANCE RESOURCES EVALUATION TECHNIQUE

I. Introduction

Background

One of the central problems that has challenged logisticians' skills and imagination from the very birth of air forces is the sizing of the support needed to sustain the operational capability of deployed air units.

Rapid response, mobility and flexibility are among the most important characteristics that strategists and operational planners seek to exploit when applying air power. Because aircraft can rapidly launch an ample variety of weapons at a wide scope of targets, these seem to be inherent features of the aircraft themselves. However, these valuable characteristics of air power do not emerge only from the intrinsic traits of airplanes, but from the coordinated effort of an operational and support system.

While this support system makes possible the projection of air power, it may also limit its magnitude or hinder its ability to move. Given a particular level of technology, the attempt to reduce the logistics support deployed to back the operations may result in a degradation of operational capacity -aircraft grounded due to lack of resources. On the other hand, too many resources are expensive to acquire and maintain and difficult to transport.

Sizing the means needed to accomplish its mission becomes the foundation over which an Air Force structures its overall peacetime structure. Therefore, when logistics decision makers are determining the resources needed to support an air campaign that may be very limited in time span (weeks or months), in reality they are shaping an effort that society will have to bear for a long time, probably decades. Now we can appreciate the complete impact of an incorrectly sized of logistics support infrastructure. If it is too low, the military capability may be reduced, which in turn may preclude the attainment of national objectives. If it is too high, the long-term economic development of the country may be jeopardized.

Immersed in the same general environment and undergoing intense pressure from shrinking budgets, the Argentine Air Force (AAF) has undertaken the task of reviewing its logistics doctrine with the aim of supporting its mission on the basis of a better designed resource structure. In this regard, a new Logistics Regulation coded as RAC 9 was issued in 1997. This document emphasizes the importance of an adequate sizing of logistics support, by establishing the necessity of planning Logistics Units of Deployment (LUD) (Argentine Air Force, 1997:22-23). These LUDs must encompass all resources needed to sustain aircraft war operations during a given period, including: personnel, support and test equipment, documentation, supply support, facilities, computer resources and services. During peacetime, the AAF must acquire and maintain in a ready-to-use status all resources that are needed to constitute and sustain the different LUDs during a war contingency.

General Problem Statement

The AAF has not yet established a method for determining the capacity that a LUD must have to accomplish all the logistics functions needed to support aircraft activity in a given war scenario. Therefore, the need for establishing such a method has risen.

The current AAF environment is characterized by resource constraints that will affect logistics decision-makers twofold. First, scarce resources will have a high incidence in the output of the planning process; limited human and physical means will lead to few options to materialize the logistics support. Second, a restricted amount of skilled human resources, limited computer systems and low compatibility of existing databases will bound the planning process itself.

The RAC 9 also defines the criteria that must be observed during the logistics planning process. Among them the following are relevant to this study:

- A logistics plan must support the operations plan (strategic or tactical) from which it derives;
- All necessary resources must be predicted;
- Unnecessary duplication of efforts must be avoided;
- The system must be efficient.

The problem that logistics decision makers are now facing can be conceptualized as follows: *to develop a model able to determine the capacity that a Logistics Unit of Deployment must have in order to support wartime activity of an Air Unit.* According to the criteria contained in RAC9 and the constraints that the current AAF environment

imposes over logistics decision-makers, it seems reasonable that the model should adhere to the following guidelines:

- Capacity must be expressed in terms of resources needed, including: personnel, support and test equipment, documentation, supply support, facilities, computer resources and services;
- It should be linked to the operational plan, which must define the type and magnitude of the Air Unit, planned activity, location, etc;
- It should be linked to the overall logistics plan (maintenance concept, distribution system, inventory policy, etc);
- It should be easy to understand and apply;
- It should be easy to implement.

Research Objective

The aim of this research is: *to develop a reduced-scale spreadsheet model able to compute the capacity of the aircraft maintenance function and its related supply support that a Logistics Unit of Deployment must have, in order to support wartime activity of an Air Unit.*

Research Scope

The main ideas that the research objective encompasses will be analyzed in the following paragraphs, in order to clarify the intention of this work.

A logistics model may be conceptualized as the intersection of functional areas (maintenance, supply/inventory, transportation, etc), methodologies of operations research (simulation, mathematical programming, network methods, statistical and

probabilistic methods, heuristics, etc), and measurement functions (individual functional measurements, cross functional peacetime measurements, and cross functional wartime capability) (Drezner and Hillestad, 1982:4). The analysis of the research objective from this perspective reveals that the intention is to develop a *maintenance resources evaluation technique* (MRET) model having a limited objective, applicable to two particular functional areas, and with a defined method of implementation; the expected scope of the model is also limited.

Model Objective. The first point that must be stressed is that the model is intended to compute resources needed to support a given amount of wartime activity for a particular air unit. It is neither devised as an optimization tool with respect to any particular peacetime functional criterion, nor conceived to evaluate internal efficiency measurements. Instead, the model is oriented toward the attainment of predetermined wartime capability, which implies the use of a cross-functional wartime capability measurement criterion.

Model Functional Areas. Two functional areas are explicitly cited in the research objective: maintenance and related supply. Maintenance activities are the main cause of consumption of logistics resources during the operational stage of the life cycle of prime mission equipment. The model should be able to calculate the resources needed for maintenance activities (personnel, test and support equipment, facilities, and technical data).

For the purpose of this work, maintenance is understood as "...all actions necessary for retaining a system or product in, or restoring it to, a desired operational

state" (Blanchard 1997:15). Corrective and preventive maintenance activities are included.

In order to carry out these scheduled and unscheduled maintenance actions, consumable material, spare and repair parts are necessary. The model addresses the supply of these materials and their corresponding inventories.

Method of Model Implementation. Although the operations research methodology is not defined in the objective of this study, the computer technique selected for model implementation was a spreadsheet model. Therefore, the operations research methodology available becomes constrained by the necessities of modeling the phenomenon with reasonable accuracy and of implementing it on a spreadsheet platform.

A spreadsheet platform was selected because it is a tool already available in the AAF planning environment. This fact is expected to facilitate the understanding and acceptance of the model and to reduce the learning curve effect during its implementation.

Scope of the Model. A reduced-scale model was developed. The main effort was devoted to isolating the different drivers of consumption of resources within the maintenance function and to finding valid ways to model the relationships among the drivers and their required resources. At this stage the model is not intended to manage all the complexities of a full-scale weapon system deployment, but rather to identify valid ways to model the core problem, and to demonstrate the feasibility of their implementation.

Research Questions

The following questions are identified as key to satisfying the research objective.

(1) *What variables must be used to link the model to the operational plan and to the overall logistics plan?* This question focuses the research attention on the different resources consumed, the cause of their use, and the relationships between them. Resources act as dependent variables, while independent variables were identified within the operational and logistics field.

(2) *What is the most appropriate type of model to apply, considering uncertainty and risk assessment?* This question compares the existing modeling approaches in order to reach the best tradeoff between the accuracy attainable through the use of these approaches, and their feasibility of implementation using a spreadsheet computer method.

(3) *What is the sensitivity of the results yielded by the model due to variations in the underlying assumptions?* "A model is often a simplified representation of reality" (Ragsdale, 1998:4). "There is no such thing as an absolutely valid model" (U.S. Department of Defense, 1996: Ch 2, 1). These two assertions depict the character of approximation to reality that all models have; some assumptions have to be made in order to obtain a practicable model. This research question evaluates the impact of deviations from the assumed conditions on the results provided by the model.

(4) *What data must be contained in the logistics databases to satisfy the needs of the model?* This seeks to define the data so that they can be used to design

logistics databases that would enable the operation of a full-scale maintenance capability computation model.

Overview of the Model Development Process

A model can be developed following these general steps: model requirement determination, model development planning, conceptual model development, model designing, and model implementation (U.S. Department of Defense, 1996: Ch 3, 4). In the case of this particular research, the first four stages were accomplished, and within each of them the following actions:

(1) *Model Requirement Determination*: logistics resources to be used to perform the maintenance function (dependent variables) were identified along with the causes for their use. This allowed a complete definition of what a full-scale model would be required to compute, and how the use of a resource is related to the operational activity and overall logistics field.

(2) *Model Development Planning*: the scale of the model was determined in terms of types of resources to be computed and the level of implementation needed to attain this reduced-scale spreadsheet program.

(3) *Conceptual Model Development*: the manner in which the relationships between dependent and independent variables should be modeled was established, by considering different types of models, for their expected accuracy and ease of spreadsheet implementation.

(4) *Model Designing*: the reduced-scale spreadsheet program was designed, built and tested.

Overview of the Model Verification and Validation Process

This research was developed in accordance with the philosophy of model verification and validation suggested by the Defense Modeling and Simulation Office in the Verification, Validation and Accreditation (VV&A) Recommended Practices Guide, which states that:

> Correction of errors early in the development always costs less than correction of errors later. If you are worried about the cost of VV&A, it is better to spend a little up front than a lot later (U.S. Department of Defense, 1996: Ch 2, 3).

Special emphasis was given to principles 2 and 10 stated in the same document, which establish that:

- Principle 2: "VV&A should be an integral part of the entire M&S [Modeling and Simulation] life cycle." (U.S. Department of Defense, 1996: Ch 2, 2);
- Principle 10: "VV&A must be planned and documented" (U.S. Department of Defense, 1996: Ch 2, 9).

Adhering to the general idea of integrating the verification and validation effort throughout the model development process, a set of tools aimed to accomplish this objective were defined for each stage of the development process. These tools were selected according to their applicability to each stage of the model development process and their plausibility considering data availability.

The following techniques were selected for each of the stages of the model development stages:

- Model Requirement Determination: Via *scrutiny of existing models,* a number of validated recurrent conceptual variables were initially identified. Their identification was corroborated and completed, using *Cause-effect graphing* (U.S. Department of Defense, 1996: Ch 4, 7), which allowed the confirmation of interrelationships among dependents and dependent variables. *A survey of expert opinion* was employed to assess the perceived importance of those variables within the AAF community of logistics planners.
- Model Development Plan: *Cause and effect graphing* was applied to identify the most important group of variables, whose modeling would lead to a significant but feasible model.
- Concept Model Development: *Data dependency analysis* (U.S. Department of Defense, 1996: Ch 4, 8) was applied to determine which variable depends on other variables, in order to lay out the spreadsheet program.
- Model Design: while developing the spreadsheet program, the different subprograms were tested in order to perform a *debugging* process (U.S. Department of Defense, 1996: Ch 4, 16). Then the model was verified through the application of *special input testing* (U.S. Department of Defense, 1996: Ch 4, 23) and *response reasonableness* (Banks et al, 1996: 401). Finally, the MRET was subject to *comparison testing* (U.S. Department of Defense, 1996: Ch 4, 15) by comparing its output to the results from a model built using a validated modeling technique.

Managerial Implications of this Research

The most important consequences of the development of this logistics model are the following:

- A thorough insight into the capacity-planning problem of deployable logistics units was gained, which could be applied by the Argentine Air Force in a future full-scale development of a logistics deployment model.
- After being validated in the particular AAF operational environment, the MRET could be used as a concept demonstrator and as the starting point to evaluate the feasibility of full-scale system by expanding it.
- Logistics data identified by this study could be used to design compatible and interoperable logistics databases.

Organization of the Thesis

This chapter described the background, general problem statement, research objectives, research scope, and research questions studied. It continued with an overview of the model development process, an overview of the model verification and validation process, and the managerial implications of this research. Chapter II provides a review of previous research on logistics modeling, spreadsheet modeling and a discussion of existing models for logistics resources calculation. Chapter III describes the methodology and findings related to the conceptual variable definition. Chapter IV justifies the selected modeling strategy and describes the MRET. Chapter V presents the results obtained from the model and illustrates the verification process used. Finally, Chapter VI discusses conclusions and suggests areas for future research.

II. Literature Review

Introduction

This chapter discusses existing literature about logistic modeling and establishes the framework in which this research may render a positive contribution. It begins by depicting essential notions of managerial modeling. Then, logistics modeling is analyzed. After that, relevant features of spreadsheet modeling are depicted. Finally, the conclusions of this chapter synthesize the relevant aspects found in this review.

Management Modeling

Conflicting Forces During the Modeling Process. There is a hierarchical relationship among problem solving, modeling and Management Science / Operations Research (MS/OR) tools; "tools of management science are contained within modeling, which is itself contained within problem solving" (Powell, 1995a: 89). We can think about modeling as the intersection of two different worlds. One is the world of the practitioners, where finding solutions to concrete problems is a must. They are driven by the problem solving aspect of this chain of concepts. Academicians are in the other end of the scale, the world of the rigorous development of MS/OR methods. In their environment, accuracy and validity of theoretical approaches to find solutions to general problems is the aim.

The model building process is shaped by tensions originating in both worlds. The modeler seeks generalizations that make the model suitable for many problems, while managers have to satisfy the particularities of a particular scenario (Little, 1970:B-469). Conflict between these two forces is inevitable during the modeling process. According to the Powell's hierarchy, Silver, Pyke and Peterson assert that: " any mathematical analysis must be made consistent with the overall corporate strategy and must be tempered by the behavioral and political realities of the organization under study" (Silver et al, 1998:50).

Problems with Management Models. When an organization is first considering a new particular class of models, the most important problem is to convince managers to use it (Little, 1970:B466). The main reasons why managers reject the use of models were described by Little in the following terms (1970:B467):

- *Good models are hard to find.* Models should include the managers' control variables and deliver concrete solutions;
- *Good parameterization is even harder.* High quality data and measurements are needed;
- *Managers do not understand the model.* Since mangers are responsible for outcomes, then it is not surprising that they prefer a simple analysis that they can grasp when facing real world problems. Complexity of the models tends to act as a barrier to understanding;
- *Most models are incomplete.* They do not encompass all critical phenomena. This imposes a serious risk when such models are used for optimization, because of their inherent lack of fidelity.

Managers use models as part of an analysis-education-decision process built around a man-model interaction (Little, 1970:B469). They compare the model's results with expectations based on their own intuition. Detected discrepancies between model results and intuition prompt the analysis of accuracy of inputs, mechanics of the model, model's assumptions, etc. This skeptical reduction of the situation to its elements works as an update of their intuition.

According to Little, such interaction should act as a principal guide during model building. If managers are to use models, then the models must be an extension of their ability to analyze the operation under their responsibility (Little, 1970:B469). Adhering to this line of reasoning, it is concluded that every effort should be made to allow managers to interact with the model in operational terms, that the model's response speed is critical, and that its influence in the analysis-education-decision process should not be diminished (Little, 1970:B470-471).

When the modeling effort has to be done under conditions of limited knowledge, Powell suggests an engineering approach to modeling (Powell, 1995a:115). Under this approach, the designer tries to develop a simple model that captures the essence of the problem. The model builder relies more on approximations and sensitivity analysis than in extensive data collection.

Logistics Modeling

Modeling Strategy Taxonomy. The main computational strategies used to model logistics processes (without intending to be an exhaustive taxonomy), include the

following (Brierly, 1993:6):

- *Deterministic*: Closed form equations. Computational speed and accuracy are the strength of this strategy.
- *Probabilistic*: this strategy may be approached through two different methods:
    - *Functional strategy*. The model operates using random functions. They are theoretical distributions of random variables through which the modeler represents a real random phenomenon.
    - *Stochastic strategy*. The model bases its operation on at least one randomly generated (stochastic) variable. Built-in pseudo-random number generators create the values of the stochastic variables. Monte Carlo Simulation, which is representative of this strategy, is a powerful tool to simulate complex processes.
- *Algorithmic*. In this case the models generally perform iterative procedures in which results converge to an approximate solution. Logistics modelers have used this strategy to find optimal solutions for maintenance or supply policies, when the logic of the modeled scenario delivers convergent results for the measurement of interests.
- *Mathematical Programming Optimization*. Under this strategy, an objective function is maximized or minimized subject to a series of constraints. When a recursive formula is used instead of the objective function, the technique is named Dynamic Programming. According to Brierly, opportunities to optimize logistics support using mathematical programming abound.

- *Artificial Intelligence Expert Systems*. When this strategy is used, the most important goal pursued by the algorithm is inferential reasoning, not calculation. It is a knowledge-based, rather than data-based strategy. Although it is a major breakthrough, it also has limitations due to its inability to reason from general axioms and lack of intuition, it is limited to using a group of facts, and heuristics taught by experts. Therefore, experts systems are confined to a well-defined knowledge domain.
- *Heuristics*: This strategy is based on "imprecise rules relating premises to outcomes" (Brierly, 1993:11), which are called heuristics. Even though the relationship is not rigorously true, the results typically approximate reality with acceptable accuracy.
- *Simulation*: When this strategy is used, one or more of the other five strategies is present. Stochastic variables are generated via random number generators. Relationships among variables are defined by deterministic formulas and an algorithm is always used. Sometimes mathematical programming is refined via simulation in order to produce optimal policies. As we can see "simulation often plays a symbiotic role" (Brierly, 1993:12) with analytical methods.

Refocusing Logistics Models. During the 1960s and 1970s most of the bases of current logistics models were established. In 1982, Drezner and Hillestad reviewed the evolution and future trends of logistics modeling, suggesting areas for improvement and stating the necessity of refocusing the modeling effort (Drezner et al, 1982). The following opportunities for improvement were identified:

- *Maintenance Replacement and Inspection Strategies*: joint consideration of personnel skills and test equipment to diagnose and isolate failures. Mean time between failures versus mean time between removal as an indicator of demand. Interaction between replacement and stockage policies;
- *Reliability*: components and elements of a weapon system to improve in order to increase capability;
- *Workload Scheduling*: mission essentiality and criticality of components, priority and expedited repair;
- *Supply and Inventory Analysis*: weapon system availability and capability, cannibalization, lateral supply, priority of repair of backordered critical components, uncertainty of arrival of transportation.

According to Drezner and Hillestad, shrinking real budgets and increasing costs have prompted decision-makers to develop models that emphasize minimization of cost within peacetime constraints. The authors suggest that this led to models that were only loosely related to operational performance and mainly focused on peacetime efficiency. They suggest that, due to an increasing uncertainty about future war scenarios, " the objectives, constraints, and structure of logistics support must now deal more directly with the dynamics, uncertainty, and mission objectives of warfare" (Drezner et al, 1982).

As can be seen from this work, the pressure at the beginning of the 1980's was directed towards more complete and complex models that were able to manage more variables in a more dynamic and uncertain environment.

<u>Need for Flexibility</u>. When analyzing logistics models, Hildebrandt and Cardell conclude that as flexibility was required in order to include more complexities of

particular scenarios, a "computer model itself becomes more a modeling tool or framework than a true model" (Hildebrandt et al 1989:4).

Hildebrandt and Cardell examined four models that link skilled maintenance manpower to military capability: LCOM (Air Force); SPECTRUM (Navy); ALOM (Army) and TSAR (Rand Corporation). They assert that "when flexible computer models are used to address manpower questions, the specific model used to address a given question is determined more by the data inputs than by the computer model per se" (Hildebrandt et al, 1989:5).

The rationale behind this assertion relies in the fact that inputs are known imprecisely and users must use judgment to select them. Therefore, "the final model and the resultant answers depend primarily on the purposes, capabilities and biases of the model users" (Hildebrandt et al, 1989:5).

A high degree of flexibility requires an intensive use of data. However, the complexity and extension of necessary data and required computer time required finally limit the flexibility of certain models (Hildebrandt et al, 1989:10).

<u>Need for Complex Logistics Models</u>. To unveil the reasons for using complex models, early works presenting the concepts of some highly elaborate logistics models that link resources to capability were reviewed.

<u>Logistics Composite Model (LCOM).</u> This is a model for simulating overall operations and support functions at an Air Force base. In this case, a complex simulation model was devised as a way to overcome limitations in the generalization of field studies. Simulation can augment and extend field test studies. "A simulation model could not only replicate the field test environment in order to extend the test results over a

longer period of time, but also apply to other aircraft, operational and logistical support environments, postulated maintenance and support policies..." (Fisher, 1968:3).

Base Operation-Maintenance Simulator (BOMS). This model simulates the essential characteristics of an Air Force base (SAC, B-52/KC-135). The stochastic behavior of variables along with complex relationships among numerous relevant variables is the main cause of the model's complexity. In addition, the complexity of the environment prevents the modeler from identifying safe assumptions to simplify the model. While reviewing the reasons for this BOMS modeling strategy, Ginsber mentions:

- "A large number of relevant (i.e., having non-trivial effect on the system) factors which interact with each other in a complex manner", and "A number of elements in the system whose behavior is stochastic" (Ginsber,1964:2);
- "In base maintenance management, it is unclear what assumptions can safely be permitted" (Ginsber, 1964:2). It is unclear what aspect of the real process could be omitted without affecting the validity of the outputs (Ginsber, 1964:5).
- "The principal advantage of using the simulator is that it predicts the future, a far more useful function than analyzing the past;" (Ginsber,1964:4)
- The necessity of incorporating many features of base processes in order to permitting test of a wide range of policies.

Planned Logistics Analysis and Evaluation Technique (PLANET): PLANET is a simulation model that can examine interactions among aircraft design, operations and logistics support of various weapon systems in a single or multi base

scenario. It was designed to help managers understand the operation of the systems and find a rationale for effective and efficient resource allocation (Voosen, 1967:v).

The size and complexity of a model increases as a function of the interrelationships to be considered. Therefore, reality must be scaled down in order to make it manageable. Simulation is a representation of reality; it is based on what designers think are the key elements. As a consequence, "one cannot say a priori that one model is "better" than another" (Voosen, 1967:1).

Support-Availability Multi-System Operations Model (SAMSOM). This model simulates weapon system and logistics support events at one or more bases during peace or wartime. It helps estimate unit capability and limitations to meet selected operations objectives (Smith, 1964:1). The cause for this tool's complexity is the necessity of exploring policies, postures and concepts in great depth and detail, which is depicted by Smith:

> The purpose in developing SAMSOM was to provide a simulation tool to the Air Force with which it can examine a wide range of aircraft operation postures and concepts and logistics support policies in considerable depth and detail, specially as these concepts and policies interact with reliability and maintainability parameters and with manpower and equipment requirements and utilization. (Smith, 1964:v)

The complexity of this model challenged the 1960's state of the art in logistics model development. "SAMSOM I program has become so complex that it is very difficult to change or broaden its scope in any way, using the language in which was programmed" (Smith, 1964:vi).

Theater Simulation of Air Base Resources (TSAR). TSAR is a simulation model designed to analyze the interaction among on-base resources and the capability of the air base to generate aircraft sorties in a dynamic, rapidly evolving wartime environment (Emerson, 1982:v). In this case, the dynamics and great level of detail that the model is intended to capture prompts its complexity. Extensive detail is incorporated to model the response of an airbase to the damage inflicted by an enemy attack in a multi-base scenario that includes mutual assistance during a crisis (Emerson, 1982:2).

Reasons for Simplicity. Following the concept that models must assist managers to make decisions in the particular environment they are confronting (regardless of whether a highly comprehensive model (e.g., LCOM) has been institutionalized), modelers have developed simpler approaches.

Fork-Join Queuing Network Model. This model follows an algorithm strategy and applies mean value analysis of a network of queues in an iterative way. The model calculates the steady-state performance in terms of sortie rate and resource utilization.

The authors justify the selection of a simpler approach as a way to overcome some difficulties associated with simulation models. Because simulation complicates the comprehensive evaluation of operational concepts, they pointed out the necessities of carefully designing the experiment, performing multiple replications, and interpreting simulation output. This can be a tedious process (Dietz et al, 1997:153).

The fork-join model produces in a few seconds accurate performance that could take hours to obtain using a simulation model. It could be used in resource structure

analysis through its iterative application. It could also be used in conjunction with simulation to identify the starting point for a simulation search (Dietz et al, 1997:162).

System Readiness Analysis for Joint STARS Aircraft: This is a PC-based discrete-event simulation model developed to fulfill the specific needs of the Joint Surveillance and Target Radar System (Joint STARS) -an Army and Air Force program. The goal was to model the interaction of mission activities and support resources in order to identify key factors that could limit Joint STARS operations. Another goal was to study changes to the factors having the greatest influence in operational capability in terms of orbit coverage time (Moynihan, 1992:30).

As part of the Joint STARS program, a thorough search of available military simulation models was conducted. None of them fulfilled the needs of the program as the following paragraph shows:

> Many of these were too large or too cumbersome to be efficiently modified so as to address the Joint STARS mission. Other models measured the wrong figure of merit (sortie generation rate rather than orbit coverage) and did not include interdependencies among different aircraft. (Moynihan, 1992:30)

Spreadsheet Modeling

Spreadsheet Applications. The following excerpt suggests that spreadsheets have become a widely used support tool in modern business.

> Spreadsheet modeling represents one of the most pervasive and successful applications of personal computers. Since their introduction in the late 1970s, spreadsheet programs transformed the notion of end-user computing, creating a new computational paradigm that offers a unique easy of use, on the one hand, and unprecedented modeling power, on the other. (Isakowitz et al, 1995:1)

Key problems in the area of capacity planning and inventory have been successfully modeled using spreadsheets. The following are some of the applications that have been reported, detailing the area of interest and modeling strategy in accordance to Brierly's taxonomy:

- *MRP planning*: a deterministic model (Frazer et al, 1992) and (Sounderpandian, 1994);
- *Capacity/Inventory:* a deterministic model that handles uncertainty via what-if analysis (Rajen, 1990);
- *Capacity Planning and Inventory:* a deterministic model (Beverluis, 1995);
- Determining Reorder Point with Random Lead-Time: An algorithmic model (Keaton, 1995);
- *Aggregate Planning:* a stochastic model based on Monte Carlo simulation (Armacost, 1990).

Relatively large problems may be modeled using spreadsheets. With hardware state-of the-art as of 1994, spreadsheet based MRP could easily handle a few thousand parts and this magnitude is expected to increase with hardware and software development (Sounderpandian, 1994:64).

Spreadsheet Organizational Acceptance. Organizations tend to accept the use of spreadsheet-based models due to the following reasons:

- *Low hardware and software cost:* when compared with a dedicated program (Sounderpandian, 1994:63);
- *Low training cost:* Most students learn about spreadsheets in college, reducing the amount of on-the-job training needed (Sounderpandian, 1994: 63). MBA

students accept spreadsheets as a legitimate managerial tool, where they reject less familiar software (Powell, 1995a:94);

- *High screen customization flexibility:* This advantage is based on features such as cut-and-paste, drag-and-drop, insert, delete, hide, etc. (Sounderpandian, 1994:63);
- *Flexibility in generation of custom reports:* High quality charts and graphs can be easily generated (Sounderpandian, 1994:63);
- *Powerful, included data analysis tools:* such as what-if analysis and optimization via mathematical programming (Sounderpandian, 1994:63);
- Usefulness as a transition tool: Spreadsheets are excellent for attaining immediate results and gaining insight about what a dedicated software package must have (Beversluis, 1995:15).

Spreadsheet Drawbacks. The use of spreadsheets is not without disadvantages as Frazer and Nakhal pointed out. These authors have compared an MRP spreadsheet application against a dedicated software finding the following problems (Frazer et al, 1992:1-5):

- *Level of Managers' Knowledge:* Managers must have a very well developed knowledge about spreadsheet programming and the logic of the model in order to take advantage of the flexibility of spreadsheet models. Poor documentation of programs and models tend to increase this problem (Frazer et al, 1992:1);

- *Low Speed* when compared with dedicated software:

    - The spreadsheet modeler must build a model large enough for the maximum problem. Because a change in one cell may cause a large number of recalculations, particularly in the environment of a MRP application, the response time ends up being a function of the maximum designed size rather than a function of the problem that is actually being solved by the user (Frazer et al, 1992:2);

    - Spreadsheets may run slower, but the speed differences are becoming less important. In 1994, Sounderpandian replicated the same case studied by Frazer and Nakhai a found a different result --1.6 seconds recalculation time after a change instead of more than a minute reporter by the latter authors (Sounderpandian, 1994:62). In spite of this discrepancy, Sounderpandian also concluded that a spreadsheet will be slower than a special purpose MRP. "But this difference will become less and less significant as faster hardware and software evolve" (Sounderpandian, 1994:64);

- *Screen Capacity Limits for the Effective Presentation of Results:* Big spreadsheets oblige the user to navigate in order to find the area of interest (Frazer et al, 1992:4);

- *Incompatibility with other Software Programs Used by the Organization:* This reason may prohibit the integration of spreadsheet based programs within a whole management system (Frazer et al, 1992:4). In 1994, Sounderpandian pointed out that almost all Microsoft products have dynamic data exchange

(DDE), allowing the exportation and importation of data between a spreadsheet and any other software (Sounderpandian, 1994:63).

Implementing Spreadsheet Program within Large Organizations. Although large organizations tend to accept spreadsheet programs due to their ease of implementation, low cost, and flexibility, there are also important risks associated with their use in that particular environment. Isakowitz, Schocken and Lucas pointed out the following problems (Isakowitz et al, 1995:1):

- *Ineffective Documentation*: logic and documentation of spreadsheet models are often largely inaccessible to people other than the creators;
- *Weak Accountability and Face-Validity*: to support this point the authors cited the following studies:
    - Cragg and King (1993) scrutinized spreadsheets sampled from 10 organizations. They found that 25% of them contained logical design errors such as: incorrect cell references, incorrect range, incorrect use of functions, erroneous formulae, data input errors (in particular, overriding formulae with constants), failure to incorporate key factors to the model, and erroneous use of relative and fixed addressing (Isakowitz et al, 1995:3);
    - Brown and Gould (1987) and Floyd and Pyun (1987) conducted two independent studies that had groups designing spreadsheets to solve a variety of problems. They found a large error rate characterizing novices as well as experts. Furthermore, most of the individuals in the experiment had exhibited a great deal of confidence in the validity of their spreadsheet

models. "Implying that spreadsheet design errors are not only prevalent but also elusive" (Isakowitz et al, 1995:3);

- *Accidental maintenance mishaps* due to a deficient knowledge of model logic and sometimes hidden physical layout (Isakowitz et al, 1995:5).

The authors believe that the blurred lines between logical design and implementation prompt this phenomenon (Isakowitz et al, 1995:3). Spreadsheets are totally unconstrained, allowing users to construct any spreadsheet that they desire, including poorly designed and poorly documented ones (Isakowitz et al, 1995:5). The authors suggest that large organizations using spreadsheets should have a corporate spreadsheet model management system (SMMS) that can (Isakowitz et al, 1995:5-6):

- Support the construction of well-designed and well-documented spreadsheets that can communicate with other models and data resources of the organization;
- Facilitate the storage and retrieval of data sets associated with sensitivity and what-if analysis;
- Facilitate transparent access to remote databases so that data can be transferred to and from a spreadsheet without human intervention;
- Facilitate access to a repository of reusable models.

Summary of Facts

A successful model that is actually used by managers must:

- Be consistent with overall organizational strategy and tempered by the behavioral and political reality of the organization.

- Use the tools that permit the model to behave as an extension of a manager's ability to analyze the operation under their responsibility.
- Communicate clearly and rapidly with users, allowing them to perform the analysis-education-decision process in an efficient manner.

The inherent large number of relationships that exist within the logistics system of any large organization (in addition to the natural uncertainty and dynamism of warfare) has originated the tendency toward building complex military logistics models.

The complexity of the models has grown in order to:

- Permit the projections of results beyond the place and time for which data are available;
- Incorporate the intricate interactions among numerous significant variables without making restrictive assumptions;
- Explore the effect of postures, policies and concepts used in the operations and logistics fields, and evaluate their mutual influence.

Highly comprehensive and flexible models have themselves become modeling tools, which demand more skills and time on the users' part to obtain and select data and build the final model within the framework provided by the computer software.

The slow response speed tends to hinder the analysis-education-decision process and limits the application of complex models in specific scenarios.

Modelers have begun to design simpler models that attempt to overcome the low response speed and high data requirements of complex models.

Spreadsheet models using deterministic, algorithmic and stochastic (e.g., simulation) methods have been successfully used to model supply and production related problems. Relatively large MRP applications have even been developed.

Spreadsheets using deterministic or algorithmic modeling strategies are characterized by high response speed.

Conclusion

The logistics Argentine Air Force community is beginning to apply mathematical models that interrelate maintenance and supply functions in a war time scenario; therefore, managerial experience is limited as well as data available in the format required by these models.

Spreadsheet models solving partial logistics problems are numerous. However, a comprehensive spreadsheet model (based mainly on a functional probabilistic, modeling strategy) that relates operational requirements to the level of maintenance resources, supply of related material, and their physical distribution at a base to satisfy those requirements, has not yet been reported.

The feasibility investigation of implementing such a model could, at least, foster the analysis-education-decision process within the AAF logistics community, while proving the USAF insights about the potentiality of this approach.

Chapter Summary

This chapter presented and discussed relevant facts concerning management models in general as well as specific logistics models in particular. The literature of applying spreadsheet software to complex scenarios was reviewed. In addition, inherent

problems that spreadsheets face within the environment of large organizations were explored.

This review established the crucial role that mathematical models play in the analysis-education-decision process, and as extensions of managers' ability to analyze the operation under their responsibility. The inherent complexities of logistics processes and the uncertainty and dynamism that characterize war scenarios have caused a natural tendency towards complex logistics models. On the other hand, this growing complexity has become a barrier for manager-model interaction, in terms of the additional required skills and longer response times. Modelers have begun to deal with this phenomenon by designing simpler models for specific applications or to be used in conjunction with more complex ones. Spreadsheet programs, using a wide range of modeling strategies, have shown their ability to handle problems within the area of capacity and inventory planning, accounting for uncertainty via a stochastic approach. This review concluded that spreadsheet programs present a promising opportunity for producing comprehensive but still simple models.

The next chapter will address the problem of defining which dependent and independent conceptual variables that an effective model must use, to relate maintenance capability to operational activities.

III. Conceptual Variables: Methodology and Findings

Introduction

This chapter discusses the methodology used to address research question (1) and presents the results that were obtained. First, research question (1) is restated and its connection to the model development process is established. Then the general research methodology and design is explained. The implementation of each phase of the research is detailed. Finally, the findings of each phase are summarized.

Research Question (1)

This research question asks:

What variables must be used to link the model to the operational plan and to the overall logistics plan?

This question focuses the research on the different resources consumed, the causes of their use and the relationships between them; its answer *per se* will fulfill the objective of the first stage of the model development process - *Model Requirement Determination.* This stage was envisioned to determine which logistics resources are used to perform the maintenance function and the cause for their consumption. This stage also seeks to find what a full-scale model must compute, and how the use of resources is related to the operational and overall logistics field.

General Methodology

The general methodology applied to answer research question (1) is known as focused synthesis and can be depicted as a "selective review of written material and existing research finding relevant to a particular research question," complemented with the discussion of "information obtained from a variety of sources beyond published articles" (Majchrzak, 1984:59).

The main difference between a traditional literature review and focused synthesis is in their purposes. Traditional literature reviews seek a research gap within a particular area of knowledge; in order to achieve this aim, a set of research studies are described. On the other hand, focused synthesis describes its sources and uses them only to the extent to which are relevant to answer the research question contributing to the overall synthesis (Majchrzak, 1984:60).

Another important way in which focused synthesis differs from a traditional literature review is the extent to which both methods stand alone. While a literature review is used as the background for later research, focused synthesis tends to be used alone as a tool for technical analysis. The results of the analysis are the results of the synthesis and recommendations are derived exclusively from the synthesized information (Majchrzak, 1984:60).

Research design

The research was designed following a seven-phase structure. The purpose of each of these phases is now detailed.

Phase 1: Logistics Models Analysis. Literature concerning six logistics models relating aircraft operations, maintenance resources, and supply activities were analyzed. The objective of this analysis was to identify the objective pursued by the model, the resources that were included as part of the computations, and the conceptual variables that were used to link the use of resources to operations, supply and maintenance policies or postures.

Phase 2: Analysis of Conceptual-Variable Frequency of Use. All conceptual variables found in Phase 1 were consolidated into one list that depicts the variables that modelers have used the most. The frequency with which each variable was used within a particular group was determined.

Phase 3: Conceptual Variables from a Different Perspective. The purpose of this phase was to confirm the relevance of the variables found in previous steps, through the analysis of literature concerning to particular resources and their relationship to the maintenance function.

Phase 4: Consolidation of Variables. This phase consolidated the number of conceptual variables to facilitate posterior analyses. Concepts that were realized to be a particular subset of a common, more comprehensive idea were merged into a redefined conceptual variable. When variables did not affect the relationship of maintenance resources required to accomplishing a given operational activity, they were eliminated from the analysis.

Phase 5: Incorporating the Environment of Targeted Organization. A survey of expert opinion was conducted on logistics officers within the Argentine Air Force.

Phase 6: Statistical Analysis of Survey Results. The aim of this phase was to determine the statistical significance of the inferences that can be drawn from the data obtained via survey.

Phase 7: Final Synthesis. In this stage, the information gathered during six previous phases was synthesized in order to discriminate among the relative importance of the conceptual variables.

Research Implementation

Each of the seven phases defined in the research design were implemented as follows:

Phase 1: In this phase, the following logistics models were scrutinized:

- Fork-Join Queuing Network (FJQN) (Dietz, 1997);
- Base Operations-Maintenance Simulator (BOMS) (Ginsberg et al, 1964);
- Logistics Composite Model (LCOM) (Fisher et al, 1968);
- Planned Logistics Analysis and Evaluation Technique (PLANET) (Voosen, 1967);
- Support-Availability Multi-system Operations Model (SAMSON) (Smith, 1964);
- Theater Simulation of Airbase Resources (TSAR) (Emerson, 1982).

The cited information sources are descriptive in nature and tend to provide the reader with the general picture of what the models were intended for, their general logic, main inputs, outputs, and possible applications.

The results of this phase were summarized in tables attached as Appendix A. Those tables contain: (1) a brief description of the objective of the model; (2) the concepts that the model uses either as independent or moderating variables -conceptual variables; (3) the maintenance resources that the model considers; (4) the maintenance tasks that are considered when computing the time needed to launch an aircraft sortie, and (5) the maintenance levels that are incorporated into the analysis.

As part of the synthesis process, conceptual variables were grouped into categories according to the following criteria:

- *Aircraft Design* (AD): variables that were classified within this group depict the particular way in which the aircraft has been conceived and produced.
- *Operational Policy* (OP): this group includes the variables that are under the control of the operational planners. They depict the size of the air unit and its level of utilization deemed necessary to produce the intended military effect.
- *Maintenance Policy* (MP): this group comprises the variables that affect the maintenance function and are under the control of the logistics planners. They depict postures and criteria that shape the way in which the maintenance function is performed and resources are used.
- *Supply Policy* (SP): the variables within this group affect the supply function and are under the control of the logistics planners. They depict postures and criteria that determine the way in which the supply function is performed and resources are distributed.

- *Secondary Logistics* (SL): these variables are related to the maintenance of physical resources needed to perform the aircraft maintenance function, which can affect the availability of such resources.
- *Environmental* (E): this category encompasses variables related to weather conditions that may affect the amount of activity actually performed by the air unit, resources needed to support maintenance actions or the time to perform them.
- *Enemy action* (EA): variables within this group are related to hostile actions carried out by the enemy that may affect the number of maintenance actions to be performed on the aircraft, support equipment and facilities (secondary logistic) or the availability of maintenance resources.

<u>Phase 2</u>: the results of this phase are presented in Appendix B. An initial table summarizes the conceptual variables that were found within each group. Then, and for each variable group, a table depicting the relationship among variables and models in which they were found and a graph of their frequency of use is presented.

<u>Phase 3</u>: The maintenance resources taken into consideration by the scrutinized models were analyzed from a frequency of use standpoint. For those resources that were found having a high frequency of use, additional sources of information were reviewed in order to construct cause-and-effect diagrams that depicts the relationships among such resources and their cause of use. Appendix C shows the results of this phase. Table C1 summarizes the maintenance resources taken into consideration by the considered models and the frequency of use by each model. From the analysis of Table C1, it can be

concluded that personnel, aircraft ground equipment and spare parts were found present in all models considered; therefore, cause-and-effect diagrams were constructed for each one of then and the results included in the same appendix. For this part of the research a different set of documents were used regarding the following resources:

- Manpower: (Gotz and Stanton, 1986) and (Hildebrandt and Scott, 1989);
- Spare Parts Supply: (Shebrooke, 1968) and (Muckstadt, 1973);
- Support Equipment: (Havlicek, 1997) and (Katrenak, 1996).

The cause-and-effect diagrams represent only variables that were found in the aforementioned documents. The categorization of such variables and the relationships that are depicted by the diagrams were derived from the readings and complemented with this author's personal experience.

Phase 4: During Phase 1, Logistics Models Analysis, 51 variables were classified. In order to facilitate the analysis several of them were merged into more comprehensive concepts. A few, because of their financial nature, were suppressed under the rationale that, although useful in trade off analyses, they do not directly take part in the computation of resources needed to perform a given air activity. In that way, the number of variables was reduced to the 30 shown in Table 3-1, whose definitions are detailed in Part III of the survey instrument. The instrument is shown in Appendix D.

Phase 5 : The objective was to seek the opinions of AAF logistics decision makers about features that a logistics model should have in order to be an effective decision support tool. A survey was conducted with the objective of requesting opinion on three areas: (1) desirable model characteristics; (2) resources to be computed, and (3)

important variables to include. The second and third parts of this survey are relevant to this chapter. The survey instrument is included as Appendix D.

Table 3-1. Consolidated Conceptual Variables

V. Group	Conceptual Variable
AD	Reliability parameters
AD	Repair time distributions
AD	Required resources
AD	Alternative required resources
AD	Failure criticality
OP	Flying program
OP	Alert schedule
OP	Mission priority
OP	Mission cancellation criterion
OP	Dispersion
OP	Probability of retaining munitions/TRAP
MP	Work shift policy
MP	Required skills level
MP	Cross training
MP	Task organization
MP	Task priority
MP	Tasks level
MP	Preventive inspection schedule
SP	Resource availability
SP	Resupply procedure
SP	Cannibalization criterion
SP	Substitutability
SL	Support equipment unscheduled maintenance
SL	Support equipment periodic servicing
SL	Facility maintenance
E	Minimum weather condition
E	Weather dependent transit times
EA	Battle damage
EA	Combat losses
EA	Base attack damage

In order to perform the survey, maintenance resources were defined according to the elements of logistics support (Blanchard 1995:12-13): (1) manpower; (2) technical

manuals; (3) computer resources; (4) supply support (consumable, reparable, TRAP, POL); (5) test equipment; (6) support equipment; (7) facilities, and (8) packaging, handling and storage. Their definition (for of this research) can be found in Part II of the survey instrument (Appendix D):

The list of conceptual variables consolidated during Phase 4 were used as independent variables in the survey.

The survey was sent to six AAF experts. Two majors, two lieutenant colonels, and two colonels responded. Having an ample background in the logistics field, all six respondents are engineers --four in aeronautics and two in electronics. All of the respondents are staff officers, and three of them have earned masters degrees in system engineering, business or information systems. Their active duty time in the AAF range from 19 to 34 years. Two have actual wartime experience, acting as aircraft maintenance officers.

Phase 6. The statistical analysis of the survey responses was performed using nonparametric methods because the assumption of normally distributed underlying populations, necessary for parametric techniques, was not supported by the results of normality tests applied to the gathered data (Wilk-Shapiro coefficient and Rank Plots).

By design this survey is a *K* related samples test, because subjects (respondents) are matched among variables. Each of the respondents assigned a rank or a score to each particular variable; thus, the treatments (combinations of respondent and variable) are not independent among each other. For example, if a respondent assigns rank number one to a particular variable, this rank is not longer available to be allocated to any other variable.

Under these conditions the Friedman two-way analysis of variance (AOV) is an appropriate choice (Cooper and Emory, 1995:466-468).

A three-step procedure was followed. First, a Friedman two-way analysis of variance (AOV) was performed. The null hypothesis was that the distributions of the scores or ranks assigned by the surveyed individuals depicting the importance of resources or variables were the same. In other words, the null hypothesis was that no difference existed in the perceived relative importance of the resources or variables. Second, if the result of the previous test lead to the rejection of the null, a Kruskal-Wallis one-way nonparametric analysis of variance was conducted and comparison of means performed at a general level of type-I error probability (alpha) of 0.05. Although this last step implies the relaxation of the assumption of a completely randomized experiment, it was done in order to have a first approximation to the conformation of homogeneous groups. Finally, when few homogeneous groups presented large areas of overlap, paired tests for a difference of means were performed using the Wilcoxon Signed Rank Test, in order to capture statistical significant differences at a alpha level of 0.05.

The survey results concerning resources and conceptual variables and their analysis are included in Appendices F and G.

Phase 7: a preference matrix (Appendix H) was developed that depicts the observed frequency of use of the consolidated variables within their corresponding variable groups and the assigned importance within the AAF.

Each of the consolidated variables received scores ranging from zero to three for each one of three different concepts: their confirmation (Phase 3), their frequency of use (Phase 2), and their assigned importance (Phase 6). Each of these concepts received a

weight factor to differentiate their relative importance: 0.3 for confirmation; 0.5 for frequency of use, and 0.2 for assigned importance. The allocation of relative importance was based on giving the most emphasis to the sources that were nearest to validated working logistics models. The importance assigned by the AAF experts got the lowest weight factor because in most of the cases the results were found to have marginal statistical significance (see Appendix G).

Findings

Due to the small sample of logistics models that were considered in this research, the findings that are presented cannot be interpreted as general tendencies within the logistics-modeling field, but are useful for this research. While other conceptual variables may be necessary to model other particular scenarios, the evidence gathered during this research, based mainly on frequency of use by validated models, suggests that most of the concepts here discussed are appropriate to model the core of the process.

Resources to Be Computed. This research study suggests that:

- Out of the eight elements of logistics support that were considered in this research manpower, spare parts, and support equipment resources tend always to be used by modelers.
- The models having the most complexity also tend to consider the interaction of facilities.
- Less importance tends to be placed on technical manuals, computer resources, and packaging, handling and storage resources.

- AAF logistics experts tend to give similar orders of importance to maintenance resources. Manpower is their highest priority, whereas facilities, computer resources and packaging, handling and storage occupy the last portion of their attention. Spare parts, support equipment, and technical manuals are placed in a secondary but still highly appreciated rank.

Conceptual Variables. This research suggests that:

- Some additional variables were found that are out of the control of operational or logistics planners, but affect the amount of maintenance resources used. For example, a complete model should consider the action of the enemy and the influence of the weather conditions.
- While the AAF logistics experts placed a great deal of importance on the effect of enemy action, only the most complex of working, validated models tend to consider this influence.
- The list of conceptual variables shown in Table 3-1, although not exhaustive, was found to provide the necessary links to the operational plan, the overall logistics plan, and uncontrolled events such as meteorology and enemy action.
- According to the results of the preference matrix presented in Appendix H, the variables received the order of importance within each group as shown in Table 3-2.

Table 3-2. Relative Importance of Conceptual Variables within their Groups

Area	Most Important	Highly Important
Aircraft Design	- Reliability Parameters	- Repair Time Distribution - Required Resources - Failure Criticality
Operational Policy	- Flying Program	- Alert Schedule - Dispersion
Maintenance Policy	- Task Level	- Work Shift Policy - Required Skills Level - Task Priority
Supply Policy	- Resource Availability	- Resupply procedure - Cannibalization Criterion - Substitutability
Secondary Logistics	- Support Equipment Periodic Servicing	- Support Equipment Unscheduled Maintenance
Weather Conditions		- Minimum Weather Conditions - Weather Dependent Transit Times
Enemy Action	- Combat Losses	- Battle Damage

Chapter Summary

This chapter presents the methodology, implementation, and results of the research performed to identify an appropriate set of conceptual variables that, acting as dependent or independent variables, are significant to model the proposed scenario. The analysis of existing validated models within the DoD environment allowed the identification of those variables. AAF logistics experts were surveyed to determine the importance that they assign to the identified variables. The information was then synthesized and evaluated to arrive first at a group of maintenance resources (dependent variables) commonly considered, and then to a consolidated set of 30 conceptual variables useful to link the model to the operational plan, the overall logistics plan, and

uncontrolled situational events. Finally, the relative importance of those variables within each group was addressed. At this point the Requirement Definition stage of the model development process was ended and useful information for establishing the Model Development Plan (next step in the process) prepared.

The next chapter addresses the problem of selecting an adequate modeling strategy and developing the MRET.

IV. Model Development

Introduction

This chapter presents the methodology used to address the second and fourth research questions and describes the MRET. First the research questions are presented and their relationship to the model development process established. Then the general research methodology, design and results related to modeling strategy selection are detailed. Finally the model development methodology and the model are described.

Research Questions

The second research question is the following:

What is the most appropriate type of model to apply, considering uncertainty and risk assessment?

This question prompted a comparison of existing modeling strategies in order to reach the best tradeoff between the accuracy attainable from these approaches, and their feasibility of implementation using a spreadsheet computer method. The answer to this question is directly related to stage three of the model development process - Conceptual Model Development. This step determines how variables should be modeled, considering the particularities of different modeling strategies taken into account and their expected accuracy and feasibility of implementation.

Before attempting to develop the conceptual model, it was necessary to establish its scale in terms of types of resources to be computed and the level of implementation to

be attained by an effective reduced-scale spreadsheet program. These decisions were made as part of the Model Development Plan stage, using the conclusions presented in Chapter III. Once the feasible scope of the model and its modeling strategy were defined, the MRET was developed. In this way, the last step of the modeling process -Model Design- was completed.

The fourth research question is:

What data must be contained in the logistics databases to satisfy the needs of the model?

The answer provides the organization and the necessary guidelines to gather, store, and maintain the information that is needed to run the model, for both its current state and for its foreseeable evolution.

Modeling Strategy

General Methodology. Focused synthesis was used to identify an appropriate modeling strategy. This method was already discussed in Chapter III when applied to the determination of dependent and independent conceptual variables. Now the focus of the synthesis was on the suitability of different modeling strategies to represent the phenomenon under study using a spreadsheet program.

Research Design. The literature describing logistics models, supplementary readings and Part I of the survey of expert opinion were considered. The scenario to be modeled was first defined. Second, according to the features of the scenario and the categorization of mathematical models presented by Ragsdale (1997:6), a general modeling approach was selected. Third, specific literature about this modeling method

was reviewed in order to confirm the applicability of this technique to this particular scenario and to identify its advantages and disadvantages. Fourth, the opinions of AAF experts on logistics planning was surveyed, to identify their expectations about what characteristics a logistics model should have in order to be an effective aid to the decision making process. Fifth, the modeling strategies presented by Brierly (1993:6) were used according to their contribution to key success factors in modeling implementation. Sixth, the results were synthesized and a modeling strategy selected.

Results.

Scenario characterization. Wartime maintenance activities at a deployment location can be typified by these three concepts:

- *Dynamism*: meaning that rapid changes in the level of activity are a principal ingredient of the situation (Emerson, 1982:2);
- *Uncertainty*: the value that certain variables are going to take at any defined point in time is unknown; their behavior is stochastic in nature (Ginsberg, 1964:2);
- *High Complexity*: an intricate interrelationship among variables complicates the conceptual simplification of processes; it makes unclear what part of the procedures could be omitted without detriment to the validity of the conclusions (Ginsberg, 1964:2).

General Category of Models. Rasgdale (1997:6-7) describes the suitability of mathematical models categories according to two features of the situation that the modeler is facing: the feasibility of defining the relationships among dependent and independent variables, and certainty about what values those variables are going to take

on. Although the relationships among variables in the AAF are complex, they can be established. On the other hand, the values of an appreciable number of variables are out of the decision-maker's control and are often unknown. Under these conditions of known relationships and unknown or uncertain values of variables, descriptive mathematical models are advised as most appropriate, and simulation and queuing modeling techniques are recommended.

Simulation Models. Because simulation modeling was found to be applicable to the AAF scenario and it is frequently used to model logistics problems (see Chapter II), its inherent advantages and disadvantages are now illustrated.

Simulation models are an appropriate tool when: (1) closed form solutions are not able to analyze all the complexities of the system; (2) analytical tools need to be validated, and (3) the impact of new designs or policies needs to be evaluated (Banks et al, 1995:4).

The pros and cons of simulation are summarized as follows (Schuppe, 1991:232-235):

As advantages, it can be stated that simulation:

- allows complex systems to be addressed;
- provides means of evaluating existing systems under new, projected conditions;
- provides means for examining design alternatives;
- facilitates experimental control.

As disadvantages we can mention that simulation:

- is only a descriptive technique: it does not lead to an "optimal" answer. Nevertheless, it is specially useful to address what-if questions;
- only gives estimates of true answers;
- can be expensive to develop, maintain and run; the lead time to get the answers is a critical aspect;
- requires a complex validation process in order to achieve management credibility and acceptance.

Expert Opinion Survey. In Part I of the survey carried out within the AAF logistics planning community, experts were asked to rank a set of desirable characteristics of a logistics model. These characteristics were identified as Little (1970: B-470) and Silver, Pyke and Rein (1998:51) suggested: (1) understandable; (2) complete; (3) evolutionary; (4) easy to control; (5) easy to communicate with; (6) robust, and (7) adaptive. The definition of each of these terms can be found in Part I of the survey instrument -Appendix D. Regretfully, the results of this survey were inconclusive, because neither statistical nor practical significant differences among the ranks assigned by the respondents could be detected (Appendix E).

Modeling Strategies. The modeling strategies presented by Brierly (1993:6) were examined from the perspective of their contribution to key success factors for model implementation, as well as their feasibility of implementation on a spreadsheet platform. The opposite to what Little mentions as the main problems for management acceptance and use of models were used as key success factors (Little, 1970:B-469). These factors depict the following characteristics of the modeling strategies:

- completeness: whether all the relevant relationship of the scenario are represented;
- understandability: the ability to explain the underlying computational mechanism and assumptions;
- ability to deliver concrete answers: appropriateness to provide an unambiguous result with direct application;
- capability of functioning with low amounts of data: the ability to give a valid and useful response when little data is available;
- speed of response: ability to compute the response rapidly so that the manager's analysis-education-decision process is enhanced by the use of the model.

The contribution of each strategy toward the fulfilling these key success factors and their feasibility of implementation on a spreadsheet were judged by this author; considering their applicability to the AAF logistics planning community. The contribution of each strategy toward fulfilling the key factors was rated using a three level scale: high (H), intermediate (I) and low (L). The results are shown in Table 4-1. These rates synthesized what the literary review exposed as modeling strategy strengths and weaknesses as well as the personal opinion of the author of this thesis about the AAF organizational environment.

Table 4-1. Modeling Strategies Comparison

Modeling Strategy		Key Success Factor for Model Implementation					Ease of implementation on spreadsheet
		Completeness	Understandability	Ability to deliver concrete	Capability of functioning with low	Speed of response	
Deterministic		L	H	H	I	H	H
Probabilistic	Functional	I	I	H	I	H	H
	Stochastic (Monte Carlo)	H	I	L	I	I	I/L
Algorithm		I	I	H	I	I	I
Mathematical Programming (optimization)		I	I	H	L	H	I
Heuristic		L	H	H	H	H	H
Simulation (Discrete Event)		H	L	L	L	L	L

<u>Model Strategy Selection</u>. Considering the dynamism, uncertainty, and high complexity characteristics of the scenario, simulation provides the modeling strategy most suitable to achieve a high degree of model completeness. Given that a time-dynamic discrete event simulation is difficult to implement on a spreadsheet, a Monte Carlo simulation approach appeared more appropriate to amalgamate both desirable effects in one tool - an acceptable degree of completeness and a manageable level of complexity. As was already pointed out in Chapter II, "simulation often place a symbiotic role" (Brierly, 1993:6), so that other techniques are also needed to fully describe the relationships. The model was expected to combine deterministic, functional

probabilistic and heuristic elements to take the most advantage of their suitability to provide concrete and high-speed responses, enhancing the manager's analysis-education-decision process. Table 4-2 summarizes the modeling strategies that were selected.

Table 4-2. Selected Modeling Strategies

	Modeling Strategy	Desirable Effect
Main	Stochastic (Monte Carlo Simulation)	To attain an acceptable degree of completeness while keeping instrument's complexity low enough to facilitate its implementation on a spreadsheet platform.
Auxiliary	Deterministic Functional Probabilistic Heuristic	To deliver concrete and high-speed responses, enhancing the manager's analysis-education-decision process.

<u>Model Conceptualization and Design Methodology</u>

In this process, Powell's engineering approach to modeling was used. This method centers its attention on the use of modeling heuristics (Powell, 1995a:115). Among them, decomposition and prototyping were extensively used during this research. Decomposition seeks to divide complex problems into smaller and more manageable ones, which are simpler to attack and solve. Prototyping consists of developing a working example of the model, which enables the designer to test strategies while gaining insight in the problem structure. Prototypes are also useful to communicate with future users and let them refine the specification of their needs through the interaction with this working model (Powell, 1995a:116-117).

The prototyping approach was also found to be congruent with the Spiral Development Cycle for models and simulation. This method employs an iterative

process that attempts partial implementations of the systems that meet what are thought to be the system's requirements. The prototype is then used and evaluated by users in order to understand the requirements better (U. S. Department of Defense, 1996: Ch 3, 10).

The use of evolutionary prototyping for the model design was not only a useful technique for this early stage of the model development, but also was envisioned as the methodology for model implementation. Using the same method for these two phases of the model's life cycle seeks to smooth the transition from one to another, and to enable the participation of the users to promote their understanding and commitment.

Model Description

The purpose of this section is to describe the MRET's concept and the mathematical approach that was employed to develop it. First, the model logic is described. Then the mathematical formulation is detailed. Finally, its assumptions and limitations are stated.

Model Logic. In order to describe completely the logic used to formulate the model, its scope is first established. Second, the base physical layout and flow of resources are presented. Third, the overall model logic is explained. Finally, the description of the general computational method is described.

Scope: The model computes the probabilistic use of maintenance resources. These resources include spare parts, reparable parts, personnel, support and test equipment, and facilities whose use depends, at least in part, on whether unscheduled maintenance actions are actually required or not. As an example, we can think of a

maintenance specialist whose participation is necessary to perform the post flight inspection upon receiving the aircraft after a mission, and then is needed again to execute the pre flight inspection before the following sortie, but who may not be necessary to fix failures within the interim between these two scheduled tasks.

Air Base Physical Layout and Flow of Resources. From a physical standpoint, the model foresees a spatial distribution of maintenance resources that is depicted in the figure shown in Appendix I. Within the air base, the aircraft may be dispersed and the responsibility of maintaining a group of them assigned to a particular maintenance site. In the terminology of the MRET a maintenance site is a collection of maintenance resources needed to launch aircraft sorties. Maintenance resources are grouped in only two types:

(1) Type A: resources that can be applied to different aircraft during the preparation of a sortie; these resources are essentially reusable in the interim between two sorties. Examples include personnel, support equipment, test equipment and facilities.

(2) Type B: resources that are used exclusively for one aircraft at a time. Examples include spare parts and reparable accessories. These resources are not reusable in the interim between two consecutive sorties; after they are assigned to a particular aircraft they cannot be reassigned (cannibalization is not permitted).

Each site may have a different number of aircraft to maintain as well as a different amount of each resource type. If the demand for resources at a maintenance site is greater than their availability, the maintenance site has to request the provision of such

resources from a central facility. If a class-B resource is not available, then the base is in a stock out condition and therefore the aircraft is not immediately recoverable. This implies a zero cannibalization supply policy. When a class-A resource is not available at the central facility, it is assumed that it has already been assigned to another site. In this case, the resource may be obtained directly from the other site when it is no longer needed there. Dotted arrows in Appendix I figure denote the flow of type-B resources, while solid arrows depict the possible flow of class-A resources.

Summarizing, when a maintenance resource is required at a particular site there are different ways to get it, and with each of these ways there is an associated time delay incurred when resources are moved from their original locations to the aircraft that is requiring them. These time delays are characterized for each resource type as follows:

- Class-A resources:

    - Resource is available at site. The time is the delay necessary to move the resources from the site to the aircraft (the minimum possible time).

    - Resource is not available at site but is obtainable at the central facility. The transit time is the delay necessary to move resources from the central facility to the aircraft.

    - Resource is neither available at site nor it is obtainable at the central facility. The resource must be obtained from another site that has finished using it.

- Class B resources:

  - Resource is available at site. The time is that necessary to move the resources from the site to the aircraft (the minimum possible time).

  - Resource is not available at site but is obtainable at the central facility. The transit time is that necessary to move resources from the central facility to the aircraft.

<u>Overall Model Logic</u>. The model applies a static stochastic strategy that requires as initial data:

- the composition of the Air Unit and its planned activity (number and type of aircraft, sorties to be flown, configurations etc);
- scheduled maintenance activities to recover aircraft and get them ready for the next sortie;
- network of activities needed to recover the aircraft;
- resources need to perform the scheduled maintenance actions;
- critical failure modes and their rates of occurrence (failure rates);
- Resources needed to fix failures;
- time needed to perform scheduled and unscheduled maintenance actions;
- the total number of resources available of each type and physical distribution among the maintenance sites and the central facility.

The MRET computes the quantity of aircraft that have a 95% probability of being recovered within given time intervals. This computation is done for the mission in the most critical moment of the planned activity, which is the point in which the load

profile (total working time needed to recover the number of aircraft required for the next mission, divided by the clock interval time between sorties) reaches its maximum.

If the computed number of recovered aircraft is less than the minimum tolerable, then the level of resources, their distribution, the geometry of the aircraft dispersion or the planned level of activity should be changed and the model recomputed until the desired level of probability is achieved. The main idea is to adjust the level of resources to avoid their becoming a bottleneck during the critical phase of the operation. Therefore, slack capacity will occur in non-critical periods.

General Computational Method. The method of computation is shown in Appendix J. It begins with the definition of the network of scheduled and unscheduled activities needed to recover the aircraft after a mission has been completed and get them ready for the next mission. The network is probabilistic, because an aircraft may undergo only scheduled maintenance actions with probability equal to its reliability, but it may also be subject to unscheduled maintenance actions (failure repairs) with a probability equal to its system failure probability.

Given that the mean and variance of each unscheduled task time distribution and failure rates are known, then the mean and variance of the unscheduled down time (UDT) of an aircraft may be computed following the functional probabilistic method that is presented in next section -Mathematical Formulation.

After an aircraft's mean recovery time and variance are computed, the execution of the network of activities defined in step one is simulated for the number of aircraft that have completed the previous mission and must be prepared for the next task. Each scheduled maintenance task's completion time is randomly drawn from a triangular

distribution. Each triangular distribution's minimum, most frequent and maximum times are a function of the level of resources assigned to each task. For the unscheduled maintenance tasks, completion times are randomly generated assuming a Lognormal distribution with mean and variance equal to the computed mean and variance of UDT. The simulation is replicated in order to get a 95% confidence interval of the number of aircraft that can be recovered for pre established time intervals. The number of replications was defined to assure that the difference between the upper and lower limit for the mean number of recovered aircraft in any interval is lesser than or equal to one aircraft. The MRET output is the upper and the lower limits of the number of recovered aircraft for different time intervals between sorties. Logistics and operational planners can use the model's result to determine if the considered mix and distribution of resources is able to satisfy the operational needs within the restrictions imposed by the base physical geometry.

Mathematical Formulation. The mathematics presentation of the MRET model is divided into the following steps: general approach, computation of mean and variance of the unscheduled maintenance down time (UDT) at aircraft level, computation of mean and variance of UDT at maintenance site level, and computation of mean and variance of UDT at component level.

General Approach. Appendix K depicts the overall methodology developed to compute the Unscheduled down Time (UDT). UDT includes the transit time needed to gather the type-A and type-B maintenance resources, plus the time necessary to perform the unscheduled maintenance task itself after all required resources

have arrived at the aircraft. The model assumes that all resources must be obtained before the maintenance task can start.

The MRET accommodates the existence of *m* maintenance sites, with *p* aircraft per site, each of which has *n* critical failure modes. A critical failure mode is one whose repair cannot be deferred, because it affects the operational capability of the aircraft.

Each failure mode has a particular UDT associated with each repair, which depends not only on the repair time distribution but also on the transit time distribution. This in turn is affected by the availability of resources at site, at the central location, and the total level of activity that the site's aircraft have had in the previous mission. This problem will be further discussed when the transit time computation is addressed.

Assuming that the mean and variance of UDT for each critical mode is already calculated and that only one critical failure can occur at the same time in the same aircraft, $UDT_1, \ldots UDT_n$ are exhaustive and mutually exclusive events, exactly one of which must occur (because we are analyzing the case in which the aircraft has failed). We assume that only one failure can occur at a time.

In general terms, if $i=1,2,\ldots k$ events (Z_i) are exhaustive and mutually exclusive random variables, then the mean $(\overline{T})$ and variance (VAR(T)) of the resultant joint distribution (T) can be computed as follows (the development of the equations (1) through (4) is presented as Appendix L):

$$\overline{T} = \sum_{i=1}^{k} (p_i)(\overline{Z}_i) \tag{1}$$

Or

$$\overline{T} = \sum_{i=1}^{k} f_i(\overline{Z}_i) \tag{2}$$

$$VAR(T) = \sum_{i=1}^{k} (p_i)\left[VAR(Z_i) + (\overline{Z}_i - \overline{T})^2\right] \tag{3}$$

Or

$$VAR(T) = \sum_{i=1}^{k} (f_i)\left[VAR(Z_i) + (\overline{Z}_i - \overline{T})^2\right] \tag{4}$$

Where

$\overline{T}$ = Mean of joint random variable
$VAR(T)$ = Variance of joint random variable
k = number of events
p_i = Probability of occurrence of event Z_i
f_i = Relative frequency of occurrence event Z_i
$\overline{Z}_i$ = mean of Z_i

Equations (2) and (4) are applied sequentially from the inside toward the outside of the network described in Appendix K. First, the mean and variance of the UDT is computed at aircraft level, then the same computation is performed at site level. Equations (1) and (3) are used to compute the mean and variance of transit time for each failure mode.

Mean and Variance of UDT at Aircraft Level. Given that an aircraft has *n* critical failure modes and using the property that failure rates are additive for independent exponential failure distributions (the exponential distributions assume that failure rates are constant), then the relative frequency of each mode f_i can be computed as follows:

$$f_i = \frac{\lambda_i}{\sum_{i=1}^{n} \lambda_i} \tag{5}$$

Where, λ_i = failure rate of failure mode i.

UDT_i is a random variable that represents the unscheduled down time for failure mode i. Replacing $\overline{UDT}_i$ for $\overline{Z}_i$, and expression (5) for f_i in equations (2) and (4), the mean and variance of UDT at aircraft level $UDT_{A/C}$ can be computed as follows:

$$\overline{UDT}_{A/C} = \sum_{i=1}^{n} \frac{\lambda_i}{\sum_{i=1}^{n} \lambda_i} * \overline{UDT}_i \tag{6}$$

$$VAR(UDT_{A/C}) = \sum_{i=1}^{n} \frac{\lambda_i}{\sum_{i=1}^{n} \lambda_i} \left[VAR(UDT_i) + (UDT_i - \overline{UDT}_i)^2 \right] \tag{7}$$

<u>Mean and Variance of UDT at Site Level.</u> Given that each site maintains p aircraft and assuming that all aircraft are of the same type (equal failure mode rates), the relative frequency of aircraft failures at site can be computed as follows:

$$f_j = \frac{\text{E(number of failures at aircraft } j\text{)}}{\text{Total expected failures at site}} = \frac{\sum_{i=1}^{n} \lambda_i * t_j}{\sum_{j=1}^{p} \sum_{i=1}^{n} \lambda_i * t_j} = \frac{t_j}{\sum_{j=1}^{p} t_j} \tag{8}$$

Where, t_j = time flown by a particular aircraft j in the previous mission.

When a failure occurs at a site, then one of the aircraft maintained at that site must have failed; therefore, we have again the case of exhaustive and mutually exclusive events. The probability of failure of each aircraft may differ due to different time flown in the previous mission. Given that we can compute the mean and variance of the random variable $UDT_{A/C}$ using equations (6) and (7) and again applying equations (2) and (4), the mean and variance of UDT at site level can be computed as follows:

$$\overline{UDT}_{Site\,k} = \sum_{j=1}^{p} \frac{t_j}{\sum_{j=1}^{p} t_j} * \overline{UDT}_{A/C\,j} \tag{9}$$

$$VAR(UDT_{Site\,k}) = \sum_{i=1}^{p} \frac{t_j}{\sum_{j=1}^{p} t_j} * \left[VAR(UDT_{A/C\,j}) + (UDT_{A/C\,j} - \overline{UDT}_{Site\,k})^2\right] \tag{10}$$

<u>Computation of UDT at Component Level.</u> Until now, the mean and variance of UDT_i (for each failure mode) have been considered as a given. The approach to estimate this time is now presented.

UDT is the sum of the time needed to gather the resources named transit time (TT) plus the time necessary to perform the unscheduled maintenance task UTT (see Appendix J). Assuming that the TT and UTT are independent, the mean and variance of UDTi for a particular component can be computed as follows:

$$\overline{UDT_i} = \overline{TT_i} + \overline{UTT_i} \tag{11}$$

$$VAR(UDT_i) = VAR(TT_i) + VAR(UTT_i) \tag{12}$$

Assuming that the distribution of unscheduled task completion times are known, the mean and variance of UTT can be calculated from that data. The next problem is to compute the mean and variance of TT. Figure 4-1 presents the probabilistic network of the process of gathering resources to fix a particular failure mode. This network represents the case of only one type-A resource and only one type-B resource. Node (7) denotes the completion of transit time which could only be realized if nodes (5) AND (6) are both realized. In other words both resources (A and B) must arrive at the airplane for the unscheduled maintenance task to start.

The network between nodes (2) and (5) represents the supply time, which is needed to obtain a type-B resource from a storage location. Two sources of supply are considered for the MRET: either from the site where the airplane is being maintained or from a central location. There is a time STB associated with the site and a time CTB with the central store.

The probability of obtaining a part from the site store depends basically on the number of parts kept there and the simultaneous demand from all aircraft that are being maintained at that site. The constant failure rate assumption allows us to treat the demand of resources as a Poisson process; therefore, we can define the probability of being able to supply a type-B resource at a site, written as P (STB), as:

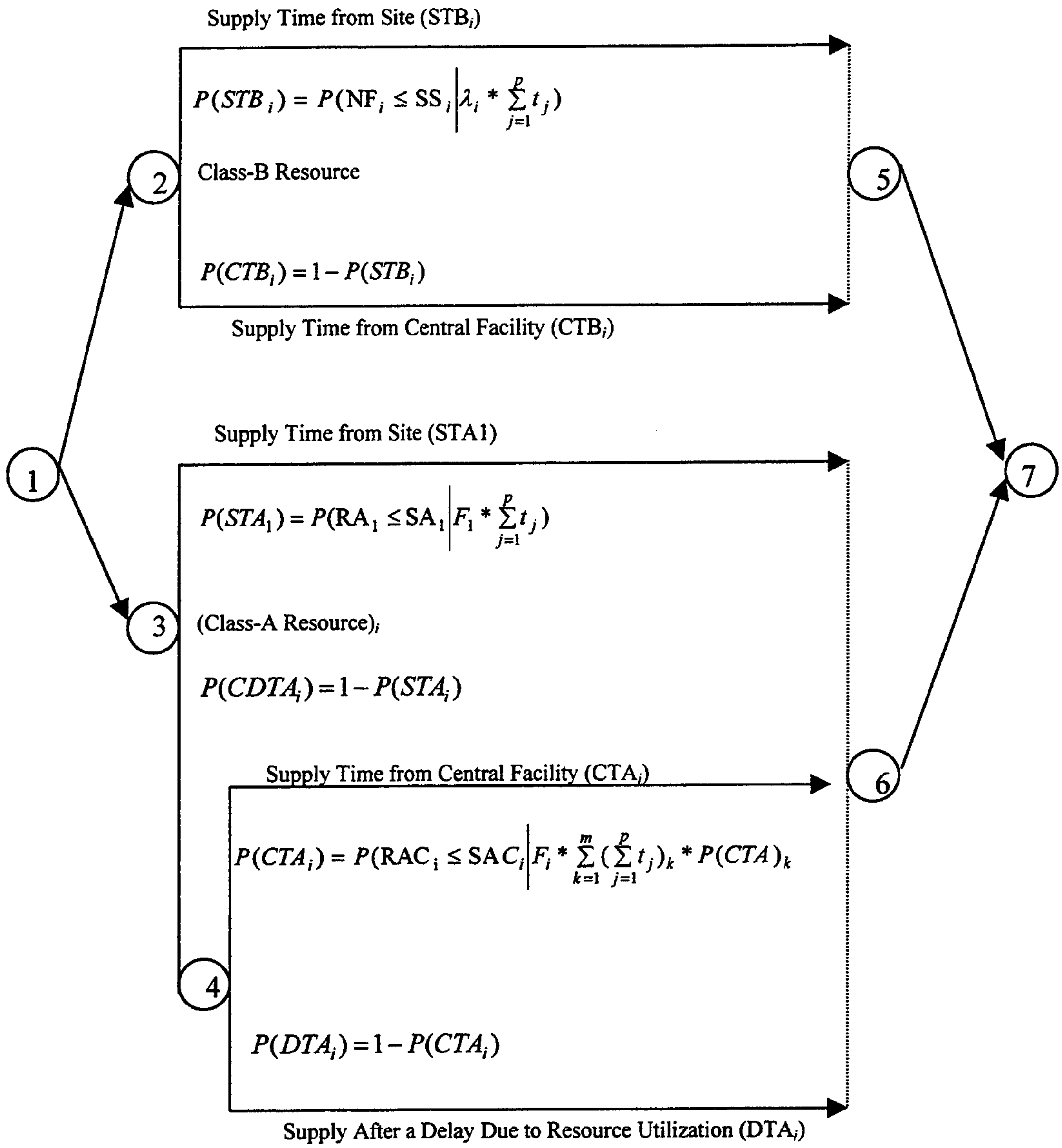


Figure 4-1. Transit Time (TT) Computation Scheme

$$P(STB_i) = P(\mathrm{NF}_i \le \mathrm{SS}_i \,|\, \lambda_i * \sum_{j=1}^{p} t_j) \quad (13)$$

Where

NF_i = Number of type i failures at site

SS_i = Quantity of type i resources stored at site

λ_i = Failure rate

t_j = Time flown for a particular aircraft in the previous mission

$\lambda_i * \sum_{j=1}^{p} t_j$ = Total demand of type i resources at site (derived from all aircraft maintained at site)

The probability that the part must be obtained from a central location is the complement of P(STB); therefore, P (CTB) is computed as follows:

$$P(CTB) = 1 - P(STB) \quad (14)$$

Given the fact that the events of supply from site or from central facility are exhaustive and mutually exclusive, we can use equations (1) and (3) to compute the mean and variance of the transit time of this type-B resource (Time from node (2) to (5)), using P (STB) and P (CTB) as weighting factors.

The network between nodes (3) and (6) represents the type-A resource gathering time, which is needed to obtain a type-A resource from a given location. For the MRET, three locations are considered: from the site where the airplane is being maintained, from a central location, or from another site after a delay due to their own use of the resource. There is a time STA_i associated with delivery from the first location (i. e. the site), a time CTA_i with the second location and a time DTA_i with the third.

The probability of obtaining a resource from site depends basically on the number of resources available there and the simultaneous demands from all aircraft that are

maintained at that site. The constant rate assumption allows us to treat the demand of resources as a Poisson process; therefore, we can define the probability of supplying a type-A resource i from the site, P (STA_i), as:

$$P(STA_i) = P(\mathrm{RA_i} \leq \mathrm{SA_i} \Big| F_i * \sum_{j=1}^{p} t_j) \tag{15}$$

Where

RA_i = Number of requerided type i resources at site

SA_i = Quantity of available type i resources at site

F_i = Frequency of utilization of resource i

t_j = Time flown for a particular aircraft in the previous mission

$F_i * \sum_{j=1}^{p} t_j$ = Total demand of type i resources at site (derived from all aircraft mainained at site)

The frequency of use of a resource i is the sum of the rates of h=1,2,...R critical failures modes that require the intervention of this resource, then:

$$F_i = \sum_{h=1}^{R} \lambda_{ih} \tag{16}$$

Where:

F_i = frequency of utilization of resource i

λ_{ih} = Failure rate of a critical failure mode that requires the intervention of resource i

h = Identifies the failure mode that requires resource i

R = Maximum number of failure modes that required resource i

The probability of being forced to obtain a type-A resource i from a central location or from another site is the complement of P (STA_i); therefore, P ($CDTA_i$) is computed as follows:

$$P(CDTA_i) = 1 - P(STA_i) \tag{17}$$

The network between nodes (4) and (6) represents the options of obtaining the resource from central location or from another site. The probability of being able to obtain a resource from central facility depends basically on number of resources available there and the simultaneous demand from all sites. This demand is that which cannot be satisfied by the resource quantity available at the sites. The constant failure rate assumption allows us to treat the demand of resources as a Poisson process; therefore, we can define the probability of supply from central facility P (CTA_i) of a resource *i* as follows:

$$P(CTA_i) = P(\mathrm{RAC}_i \leq \mathrm{SAC}_i \Big| F_i * \sum_{k=1}^{m} (\sum_{j=1}^{p} t_j)_k * P(CDTA)_k) \tag{18}$$

Where

RAC_i = Number of resources type *i* required at central location

SAC_i = Number of resources type *i* available at central location

F_i = Frequency of utilization of resource *i*

$P(CDTA_i)_k$ = Probability of obtaining the resource type *i* from central location or other site at site *k*

t_j = Time flown for a particular aircraft in the previous mission

$F_i * \sum_{k=1}^{m} (\sum_{j=1}^{p} t_j)_k * P(CDTA_i)_k$ = Total requirement of resource type *i* from all sites.

The probability of obtaining a resource from some other site is the complement of P(CTA_i); therefore, P (DTA_i) is computed as follows:

$$P(DTA_i) = 1 - P(CTA_i) \tag{19}$$

Given the fact that the events of supply from site, from central facility, or from another site are exhaustive and mutually exclusive, we can use equations (1) and (3) to

compute the mean and variance of the transit time of this type-A resource i (Time from node (3) to (6)). In this case we have to use P (STA_i) as the weight for the distribution of times from site, P ($CDTA_i$)*P (CTA_i) as the weight for times from central location and P ($CDTA_i$)*P (DTA_i) as the weight for the times from other site.

The solution for the mean and variance of times to realize networks between nodes (2)-(5) and (3)-(6) is now complete. To find the mean and variance of transit times across the whole network (between nodes (1)-(7)) imposes a different challenge due to the logic associated with node (7). In the terminology of GERT (Graphical Evaluation and Review Technique), this kind of node within a conditional network is called an AND node because all the arriving tasks must be performed in order for the node to be realized (Pritsker, 1966:268). When times in the network are random variables, no computationally feasible method has been developed (Pritsker, 1966:272 and Whitehouse, 1973:287). Using Pritsker's suggestion (1966:273), the solution of this problem was approximated using a combined analytical-simulation technique. Heuristic formulas were developed to estimate the results obtained when the logic of the AND node was simulated. A SLAM II model was built modeling the scheme represented in Figure 4-1; one triangular distribution was used to represent the supply of a type-B resource, while exponential distributions were used to represent the time to gather each type-A resource. The rationale for using exponential distributions for type-A resources relies on the fact that high coefficient of variations (CV) and distributions more skewed to the right are typical of these resources (personnel, support equipment, test equipment, etc.). Using a regression analysis of the simulation results, the main predictors of the mean and CV of transit time were found and then correction factors were applied to

extend the use of the formulas beyond the variable values observed from simulation. The following analytical expressions were designed:

$$\overline{TT} = \{K_1 * RM * [1.7443 - 0.6639 (1 - LnND)]\} * K_2 \tag{20}$$

$$K_1 = \left[0.2065\left(\frac{SM}{RM}\right) + 1.0188 + 0.0255(RM - 21{,}66))\right] \tag{21}$$

$$K_2 = 0.75$$

Where

RM = Average of the transit time means for type - A resources

ND = Number of type - A resources

SM = Transit time mean for type - B resource

$$CV = CV_{RA} [0.87667 - 0.2026 (\ln(ND))]K_3 \tag{22}$$

$$K_3 = \{[-0.0206RM + 1.6632] + 0.3078\ln(RM) - 1.2717\}\frac{SM}{RM} \tag{23}$$

Where

CV = Coefficient of variation (St. Dev. (TT)/$\overline{\text{TT}}$)

CV_{RA} = Maximum CV of type - A resources

These formulas where developed using data within the following range:

$$1 \le ND \le 5$$

$$0.586 \le \frac{SM}{RM} \le 1.847$$

$$21.66 \le RM \le 27.3$$

$$1.23 \le CV_{RA} \le 1.58$$

Assumptions and Limitations. The MRET assumptions and limitations of the model are now summarized and discussed:

(1) Zero-cannibalization supply policy. This limitation was adopted in order to simplify the model, and is based in the rationale that cannibalization may not be a practical source of parts in the most critical phase of the operation. The MRET's computation is based on the critical interval for aircraft recovery when little time is available to perform a lot of scheduled and probably unscheduled tasks; therefore a cannibalization alternative is going to be considered only in the case that it involves a short time. This model limitation will tend to make the MRET yield conservative results.

(2) The fleet of vehicles to move resources from the central location to sites or to perform inter-site movements has ample capacity. This assumption simplifies the modeling of the scenario. As a consequence the transit time (an input value for MRET), must consider the actual available fleet.

(3) Inter-site type-B resource supply is not considered. This limitation preserves model simplicity. It is based on the fact that after a mission of a typical length, having one or two parts at site yields a large amount of protection against a stock out condition at site. When the available quantity of a particular spare part is low (e. g., for a high cost part), placing it at the central location appears to be a sound policy and is represented by the model.

(4) The most critical moment of the planned activity may be derived by computing a load profile (total working time divided by clock interval time between sorties).

(5) Slack capacity for non-critical periods of operations is acceptable. The model does not determine an optimal amount of resources on the basis of efficiency of use. The philosophy of the model is to prevent maintenance resources from becoming a constraint during the critical phase of the operation -- a wartime effectiveness criterion.

(6) Constant failure rates are assumed. The system is considered to be in the flat zone of the "bathtub" curve (no variation of failure rates is considered). This model characteristic considered if it is used for long run planning purposes. A failure rate based only on historical data may not be exactly the same as the one existing at the moment of the planned operation.

(7) The unscheduled down time at site is assumed to have a lognormal distribution. This is an accepted distribution to model time to perform a task, specially in the case of "electronic equipment without built-in test capability" or "electromechanical equipment with widely variant individual repair times" (Blanchard, 1996:101).

(8) Only one critical failure at a time occurs in the same airplane, but the same or different critical failures can simultaneously occur in all aircraft at the same time. This limitation aides model simplicity; it is based on the low probability of occurrence of more than one critical failure. In addition to a critical failure, an aircraft might experience a non-critical one, in which case the MRET assumes that the non-critical failure repair will be deferred. This assumption may make the MRET produce somewhat optimistic results.

(9) Aircraft failures occur only during the previous flight. This may also produce an optimistic result; it may be partly accounted for by using a mission abort ratio to correct the number of aircraft calculated as recoverable by the model.

(10) All necessary resources must be obtained before the unscheduled maintenance task can start. This assumption will tend to yield down times longer than they really are, because the feasibility of initiating a repair with partial resources is not considered.

(11) One class-B resource and up to five type-A resources are required to fix every critical failure mode. This limitation is imposed by the heuristic used to approximate the AND node. A different approximation approach could overcome this limitation type-A.

(12) Combat attrition is not modeled.

(13) The aircraft component failure mode probabilities are independent. Failures that affect all or part the aircraft due to a common root are not considered.

(14) Type-A resources are always available; their failure is not modeled. This assumption will cause the computed down time to be somewhat lower than it really is.

(15) When a type-A resource is not available at the central facility it is supposed in use in all sites; therefore, a requesting site must always wait for the resource to become available. The possibility of a resource becoming available at the requesting site after a delay due to its own use is not considered. The likelihood of obtaining the resource from an idle resource from another site is not considered; this probability may increase as the

number of sites increases and the quantity of resources decreases. This is a conservative assumption whose effect may be more noticeable as the number of maintenance sites increases.

(16) When an aircraft is undergoing unscheduled maintenance, the random variates used for repair time during the simulation are drawn from a lognormal distribution whose parameters are independent of the number of aircraft that are actually being fixed (competing for resources). Therefore, a repair time drawn from the lognormal distribution could be a large number, even if only one aircraft is under repair.

Model Data Requirements. To operate this model the logistics databases will have to provide the following key information:

- the definition of critical failure modes;
- the Mean Time between Failure (MTBF) for each critical failure mode;
- the definition of resources needed to repair each critical failure mode;
- the definition of the scheduled (mandatory) maintenance activities to generate a sortie for each particular aircraft configuration;
- the minimum, most frequent, and maximum times to perform each scheduled task for different levels of type-A resources assigned to perform the tasks. When a group of resources is applied to perform scheduled tasks on more than one aircraft, the same times must be determined for each aircraft in the planned sequence of task completion;
- any incompatibilities for simultaneous scheduled task accomplishment;

- the minimum, most frequent, and maximum time needed to perform the repair activities associated with each failure mode;
- the minimum, most frequent, and maximum transit times for the different maintenance sites for peacetime bases, as well as for probable deployment airfields. Such time must be determined for the particular base transportation system available at the deployment site.

Although not necessary to operate the model, the following information would be useful:

- Mission abort rate. This parameter could correct the model output, in order to include failures that are discovered after the aircraft is recovered, but prior to its take off.
- Historic information about the actual time to perform scheduled and unscheduled maintenance tasks, in order to validate the repair time distributions and introduce them in the simulation of the network. This would increase model accuracy.

Chapter Summary

This chapter presented the methodology used to select the modeling strategy and to develop the MRET. Then, the MRET's data requirements were detailed.

According to Brierly's taxonomy of modeling strategies, a stochastic model complemented by a probabilistic functional approach was selected. This approach obtains a reasonable degree of completeness while keeping a high speed of response and permitting a spreadsheet implementation. The probabilistic functional approach is based

on a constant failure rate assumption, which allows treating the number of failures in any given moment as a Poisson process. The Poisson process is used to compute an expected mean and variance for unscheduled down time at maintenance the site. Due to the conditional nature of the network of tasks needed to gather the resources to accomplish an unscheduled maintenance action and its particular logic, a heuristic approximation formula was developed to compute the mean and variance of the transit times distribution. The network of scheduled and unscheduled activities needed to recover the aircraft is simulated by a Monte Carlo model, which uses a lognormal distribution to represent the unscheduled repair time. The parameters of that lognormal distribution are computed by the probabilistic functional part of the model. The MRET's outcome is the mean of the number of recovered aircraft for different intervals between sorties.

The next chapter illustrates the verification process used for the MRET.

V. Results

Introduction

In this chapter research question (3) is addressed. First, the research question is restated. Second, the MRET's verification is explained. Third, a comparison is made with a discrete event simulation using the same conceptual model logic as the MRET.

Research Question (3)

The third investigative question is:

What is the sensitivity of the results yielded by the model to variations in the underlying assumptions?

This research question evaluates the impact of deviations from the assumed conditions on the results achieved by the model. It encompasses two different aspects: verification, and validation of the results. The verification process confirms that the model was correctly implemented in the computer (i. e. it asks if the model is doing what it is supposed to do). The validation process compares the adequacy of the results to reality (i. e. it seeks to confirm whether the model is an acceptable representation of the real world).

Model Verification

After a MRET prototype was programmed on a Microsoft Excel spreadsheet, the first verification step was to debug it. The heuristic of decomposition used during the development of the model was a helpful tool for this purpose, because it allowed the

program to be debugged in small steps, where the level of interaction was low enough to predict the results that the particular computation should produce. At this point the main effort of debugging was centered on the deterministic relationships that the MRET uses. For example, the results of the probability of obtaining a particular type A or B resource (programmed using an Excel built-in Poisson distribution) was checked for different inputs with tabulated results of that distribution.

When several spreadsheets were interrelated and the recovery time mean and variance results were reached, an efficient way to verify the program was to use special input testing. The value zero was assigned to key parameters and the concordance of results with the mathematical logic of the model was verified. Finally, the partial results yielded by the program for a particular set of data were compared with those obtained by means of a manual resolution of all the equations.

When the prototype reached the Monte Carlo simulation process stage, the maximum degree of interrelationships among variables, individual spreadsheets and even workbooks was simultaneously attained. In this situation, true results were impossible to predict due to the descriptive nature of this technique. Therefore, the verification process was continued by means of special input testing and, following the suggestion of Banks, Carson and Nelson (1996:401), by judging the MRET's response reasonableness to changes in key inputs. The results of this part of the process will be presented after a brief description of the scenario for the verification process.

Scenario Modeled. The scenario includes the operation of a group of twelve aircraft using a deployment base in which two maintenance sites were established (that each maintain six aircraft), and a central facility to store and distribute type A and B

resources. All the aircraft are identical, which leads to the use of a common hardware definition, common failure modes and failure rates. Seven different scheduled tasks were defined: landing and taxi to the maintenance site, debriefing, post flight inspection, weapons unload, refueling, weapons upload, preflight inspection, and taxi and take off. The network that defines the relationships among the scheduled and unscheduled activities is presented as Figure 5-1.

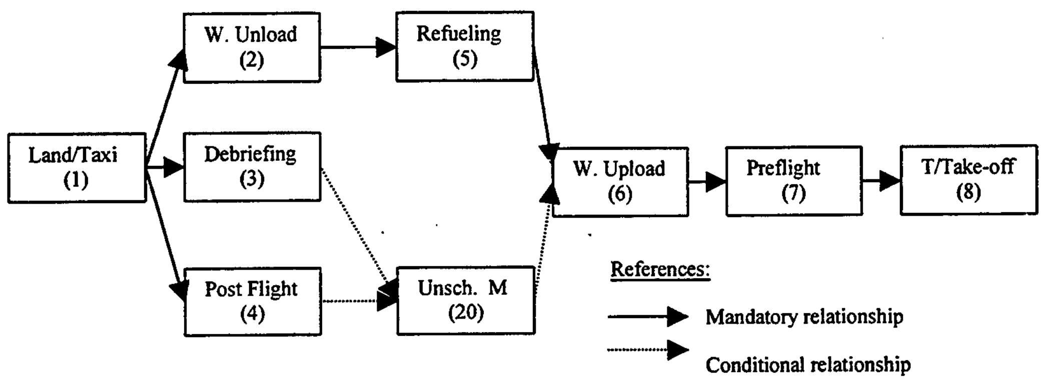


Figure 5-1. Network of Activities

For each scheduled task, three different times were defined: a minimum, a most likely, and a maximum. Two maintenance teams were defined for each site. Each team must maintain three aircraft. For each scheduled maintenance activity, particular optimistic, most likely and pessimistic completion times were defined for the first, the second, and the third aircraft that each team was simultaneously working on. These times were defined for three different levels of resources. For level-one resources (the minimum) each aircraft has different mean completion times due to the need to share resources. At resource level two (moderate), enough resources were available for the

first and the second aircraft to be served at the same time, so that their mean completion times are the same. At the maximum resources level all three aircraft can be served at the same time; in this case, all three aircraft share the same mean completion time. This definition of resource levels is completely arbitrary --while useful for this stage of the verification process, it does not constitute a model limitation. The users can define the levels in the way that best fits their scenario. Note that the model does require the definition of different minimum, most likely, and maximum times as a function of the level of pool resources for each aircraft to be maintained. Appendix M describes the data that was used to define the scenario for this verification process.

Special Input Test. A lower bound for the recovery time was found and then the case for which the model should approximate that limit was explored. The unscheduled maintenance task is conditional upon the probability of failure; therefore, when the reliability of the aircraft is very high the frequency of repairs tends toward zero. In that case the mean recovery time should approach that of a network having only scheduled tasks. That converts the network to a classical non-conditional network for which mean the completion time can be found using PERT analysis. According to the task times defined in Appendix N and the network presented in Figure 5-1, the critical path is formed by the following sequence of tasks: one, two, five, six, seven and eight. The resultant mean time for the completion of the critical path is 94.66 minutes. In order to make the model behave in a condition of high reliability, a MTBF of 100,000 hours was assigned to each of the failure modes. Under this condition the mean recovery time computed by the model was 97.35 (+2.90%) minutes; when the MTBF was 1,000,000 hours the mean recovery time was 96.79 (+2.25%) minutes. From this result it was

concluded that in this extreme condition, the model was performing close the PERT methodology solution. Further conclusions are risky due to the descriptive nature of PERT itself and errors that it might yield (MacCrimmon and Ryavec, 1964:36).

Model Response Reasonableness. This test changes key parameters in order to determine whether the model response follows a predicable trend in accordance with the characteristics of the modeled relationships. This test was performed by manipulating key parameters representative of the following phenomena: aircraft reliability, mission sortie length, distribution of resource type A, and geographical resource dispersion. The mean recovery time was the result observed.

Response to Changes in Reliability. It was expected that an increase in reliability would cause a decrease in the mean recovery time. This effect was also expected to be more noticeable as the level of resources diminishes. To check the response of the model the MTBF of each failure mode was varied from 50 to 1000 hours. All resources were simultaneously and subsequently set at level one, two, and three. Figure 5-2 shows the results. From this result it was concluded that the model's response, follows the expected general trend, for changes to aircraft reliability.

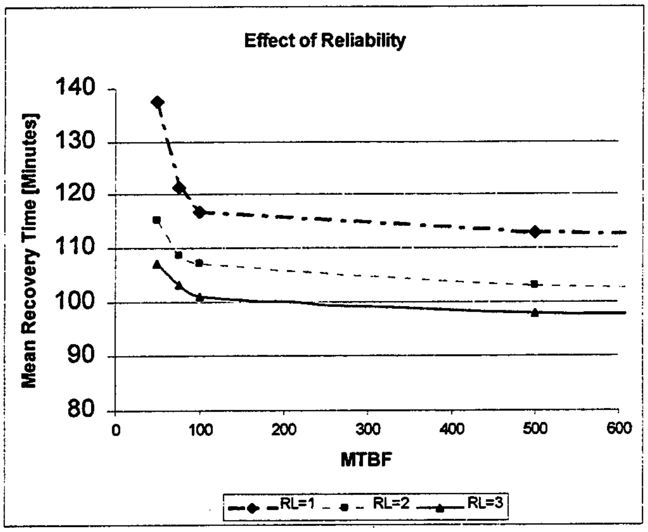


Figure 5-2. Model Response to Changes in Aircraft Reliability

<u>Model Response to Changes in Sortie Length</u>. It was anticipated that an increase in the previous mission's sortie length would cause an increase in the mean recovery time due to a greater probability of failures. This effect was also predicted to be more noticeable as the aircraft reliability decreases. To check the model's response, the sortie length was varied from 1 to 4 hours, and the mean recovery time computed using a parameter of 1000; 100, and 50 hours for the MTBF of each failure mode.

Figure 5-3 shows the results.

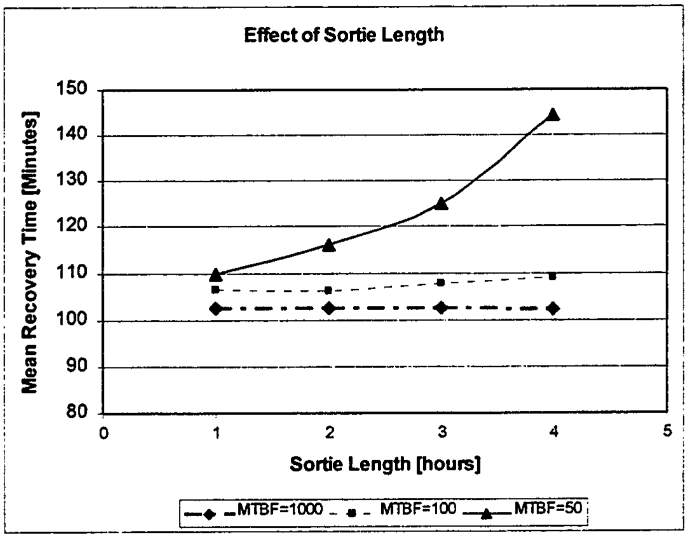


Figure 5-3. Model Response to Changes in the Sortie Length

From the results obtained, it was concluded that the MRET's response to changes in the previous mission's sortie length follows the predicted trend.

Model Response to Changes in Resource Distribution. It was predicted that as more resources are stored at site (near the aircraft), the mean recovery time would decrease. This effect was also predicted to be more noticeable as the aircraft reliability decreases. To check the model's response, for each type-A resource a total number of nine units were assigned to the base. The number of these resources that were stored at site was varied from zero to 4 and the mean recovery time computed using a parameter of 1000; 100, and 50 hours for the MTBF of each failure mode. Figure 5-4 shows the results.

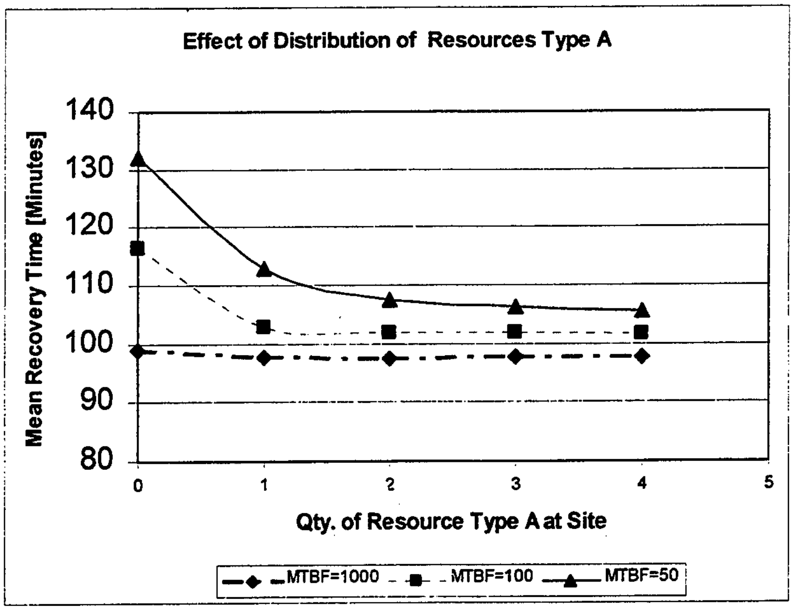


Figure 5-4. Model Response to Changes in Resources Distribution

The results suggest that the model's response to changes in the distribution of type-A resources among the central facility and the maintenance site conforms to reasonable expectations.

Model Response to Changes in Resource Physical Dispersion. It was predicted that the greater the distance between the central facility and each maintenance site, the greater the mean recovery time would be, due to an increasing delay in availability of resources. This effect was also predicted to be more noticeable as the aircraft reliability decreases. To check the model's response, the mean transit time needed to move a type A or B resource from the central facility to both maintenance sites was varied from 40 to 50 minutes (while keeping its variance constant) and the mean recovery time computed using a parameter of 100 and 50 hours for the MTBF of each failure mode. Figure 5-5 shows the results.

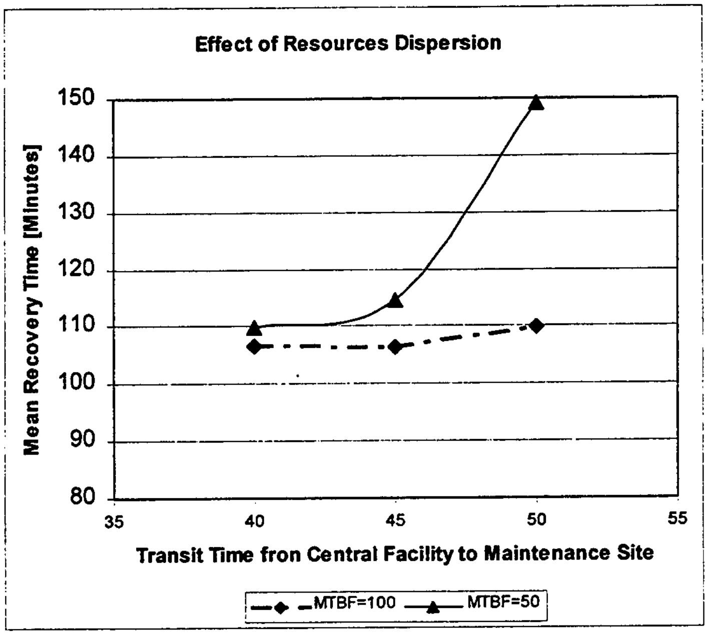


Figure 5-5. Model Response to Changes in Resource Physical Dispersion

From these results, it can be concluded that the model's response to changes in the physical dispersion of type A and B resources emulates what was predicted.

Preliminary Conclusions. After the debugging and the special input and response reasonableness tests were conducted, it was concluded that the prototype MRET performs as predicted.

Comparison with a Discrete Event Simulation Model. Although the model was shown to be performing as predicted, nothing could be yet said about the quality of its results. Therefore, a first step was to compare the MRET's output to that of another model coded using commercial simulation software. A simulation model based on the same modeling logic as the MRET was designed using SLAM II software. The idea was to maintain the models as similar as possible so that they only differ in the way the unscheduled maintenance process is modeled. Note that this comparison did not seek to

validate the model, but rather looked to determine whether the MRET's combination of a probabilistic functional technique and a Monte Carlo simulation could provide results comparable to dynamic discrete event simulation. If it did, then the better suitability for spreadsheet programming and the advantage in response speed obtainable by MRET would justify further research on this kind of model.

The SLAM II Model. This program was designed using the same conceptual model in such a way that most of the assumptions and limitations of the MRET model were applicable to it. The complete SLAM II program code is listed in Appendix N. The following assumptions and limitations that apply to the:

- Zero-cannibalization supply policy.
- Fleet of vehicles to move resources from central location to sites or to perform inter site movements has enough capacity.
- Inter site class-B resources supply is not considered.
- Constant failure rate. The system is considered to be in the flat zone of the "bathtub" curve, no variation of failure rate is taken into consideration.
- Only one critical failure at a time occurs in the same airplane, but the same or different critical failures can simultaneously occur in all aircraft at the same time.
- Aircraft failures occur only during the previous sortie.
- All necessary resources must be obtained before the unscheduled maintenance task can start.
- One class- B, and up to five of class A resources are required to fix every critical failure mode.

- Combat attrition is not modeled.
- The failure probabilities of aircraft are independent.
- Type-A resources are always available; their failure is not modeled.
- When a class A resource is not available at the central facility then it must be in use by another site; therefore, a requesting site must always wait for the resource to become available.

A comparison of the assumption and limitations of both programs shows that the main difference between the models is that MRET requires additional assumptions. The down time at site is assumed lognormally distributed, and the parameters of this distribution are the long run mean and variance computed by the probabilistic functional portion of the model. This closed solution uses the probability of obtaining resources at the maintenance site level as a function of their availability and demand modeled as a Poisson process in order to account for the competition for such resources. However, when the MRET's Monte Carlo simulation is run, it possible that a long down time at site is randomly generated from the lognormal distribution, even if only one aircraft has failed and resources are available. This is a weakness of the MRET that could introduce a discrepancy with respect to the discrete simulation model, in which long down times are only expected to be observed when actual resource contention takes place. Divergence between models that use a functional probabilistic approach versus discrete event simulation of the same scenario has been reported for the Fork-Join Queuing Network Model (Dietz and Jenkins, 1997:160) and the Dyna-Sim Model (Miller et al, 1984:16). In both cases the discrepancy was found to be greater when the load on the system was high (i.e., when resource contention is high).

Comparison Design. The experiment was designed to sense possible differences at three different levels: aircraft unscheduled down time at site, aircraft recovery time, and number of aircraft to be recovered within a given interval. The dependent variables observed included the mean and variance of down and recovery times and the mean number of recovered aircraft. The probability P(STA) of obtaining the most critical type-A resources at site was used as an independent variable. The operational variable used to change P(STA) was the failure rate of each failure mode. By increasing the failure rates, the probability of obtaining resources at site decreases due to a greater demand, which in turn increases the likelihood of multiple simultaneous requests for the same resource. Finally, the general levels of available resources were also used as a parameter. The level of resources was defined in the following way:

- Level 1 (RL=1): each of the three aircraft maintained by a team has a different mean completion time; they cannot be served simultaneously. Each site keeps one unit of each type-A resource.
- Level 2 (RL=2): Two aircraft have the same mean of completion times; they can be served at the same time. The third aircraft has a different and greater mean completion time. Each site keeps two units of each type-A resource.
- Level 3 (RL=3): Three aircraft have the same mean completion time; all of them can be served at the same time. Each site keeps three units of each type-A resource.

First a level of resources was set and then the MTBF for all the failure modes were varied from 400 to 50 hours. The results yielded for both models were tabulated and compared in absolute and percentage terms. The results are shown in Appendix O.

Unscheduled Down Time Comparison. Essentially, at this level we are comparing a static functional probabilistic model (that includes a heuristic formula for approximating the AND node logic) versus a dynamic discrete simulation model.

Mean of Unscheduled Down Time $(\overline{DT})$:

- For high and moderate resource levels (RL=3 and RL=2) and moderate to low unscheduled maintenance demand (P(STA) from 0.999 to 0.78), the $\overline{DT}$ calculated by the MRET exceeds the simulation model mean by 1.4% to 4.5%.
- At moderate resources level (RL=2) and high unscheduled maintenance demand (P(STA)=0.56), the MRET exceeds the simulation by a maximum of +16.5%.
- At low resource level (RL=1), the MRET's mean is less than the simulation's results. In the region of P(STA) that extends from 0.99 to 0.65, the errors range from -3.13 to -12.35%

Standard Deviation of Down Time:

- For high and moderate resource levels (RL=3 and RL=2) and high values of P(STA) (0.78 to .999), the MRET's standard deviation was slightly less than the one obtained by simulation (0 to -1.19%).
- When the probability of obtaining resources at site P(STA) is below 0.8, the standard deviation computed by the MRET is above the one yielded by simulation (+1.5 to +5.9%)

- When the level of resources is very low (RL=1), the MRET's standard deviation is between 32 % and 43% less than the one obtained by simulation (P(STA) ranges from 0.999 to 0.52).

General Conclusions about Down Time. The MRET's functional-probabilistic-heuristic approach tends to perform reasonably well (+/- 5% error) for moderate or high resources availability and low demand (up to 0.8 probability of obtaining resources at site). As the general level of resources decreases the error tends to increase. As the demand of unscheduled maintenance tasks increases, the probability of obtaining resources at site decreases and the MRET's results tend to diverge from simulation output. When the level of resource falls to a minimum the MRET yields optimistic results (mean and standard deviation fall below the discrete event simulation's results). The standard deviation is the parameter that diverges the most, while the MRET's mean tends to preserve a higher degree of approximation to the simulation results.

Recovery Time Comparison. Essentially, at this level we are comparing a static (Monte Carlo) simulation combined with a functional-probabilistic-heuristics approach versus a dynamic discrete-event simulation. The MRET's lognormally-distributed unscheduled down time assumption now affects the results.

Mean of Recovery Time $(\overline{RT})$:

- For all resource levels and for P(STA) values from 0.999 to 0.3, the error in $\overline{RT}$ was always positive with a minimum of 1.53% and a maximum of 5.23%.

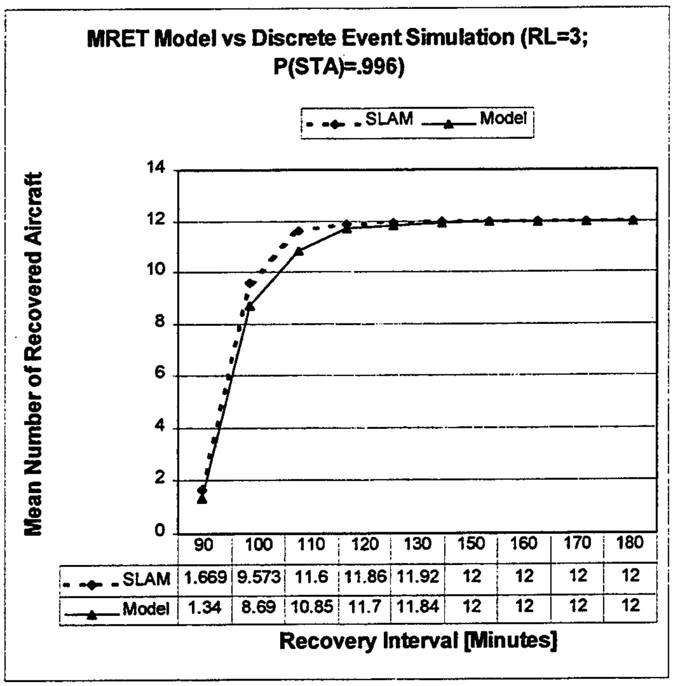
Standard Deviation of Recovery Time.

- At high and moderate resource levels (RL=3 and RL=2) and for P(STA) from 0.999 to 0.569, the error was positive with values from 7% to 28 %.
- At a low level of resources (RL=1), the difference is positive for a very low demand, and becomes negative when demand increases (+5.12% to -21.23%).

General Conclusion about Recovery Time. The mean recovery time obtained by the MRET is very close to the result obtained from the dynamic discrete event simulation model, for a wide range of resource levels and unscheduled maintenance actions demand. The mean recovery time shows low sensitivity to the errors found for the down time distribution. For example, at the extreme case where RL=1 and P(STA)=0.3, the error in the mean and standard deviation of DT are 13.31% and 60% respectively, while the error corresponding to the mean of RT is 4.42%. The error of the standard deviation appears more sensitive to the resource levels and maintenance actions demand. At a high or moderate resources level, errors are positive, while at low levels they become negative. As the demand of maintenance actions increases the divergence of results tend to increase. If we consider the whole spectrum, from high resource levels combined with low demand to low resource levels combined with high demand (minimum to maximum system load), then the standard deviation of down time error varies from 0.17% to -60.73%, while the same parameter corresponding to recovery time varies from +28.20 to -21.77%. A possible explanation for this phenomenon is that the lognormal distribution (assumed for down time) is skewed to the right for the shape parameters observed during the experiment (approximately 0.24). This assumption might have increased the variability of the results of the MRET's Monte Carlo simulation. This

increasing variability induced by the lognormal distribution may have been compensating for the negative error observed for down time.

Comparison of Mean Number of Recovered Aircraft. This is the critical point of the experiment because this measurement is the one that logistics and operational planners would use in their decision making process. Figures 5-6 through 5-11 show the curves obtained using the MRET and the dynamic simulation (SLAM II model) for different resource levels and P(STA) values.



	90	100	110	120	130	150	160	170	180
SLAM	1.669	9.573	11.6	11.86	11.92	12	12	12	12
Model	1.34	8.69	10.85	11.7	11.84	12	12	12	12

Figure 5-6. Comparison of Mean Number of Recovered Aircraft for RL=3 and P(STA)=0.996

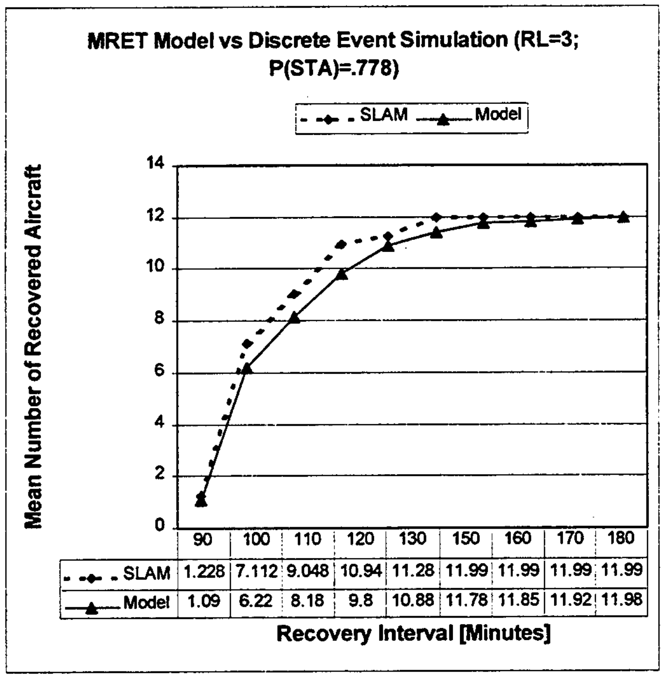


Figure 5-7. Comparison of Mean Number of Recovered Aircraft for RL=3 and P(STA)=0.778

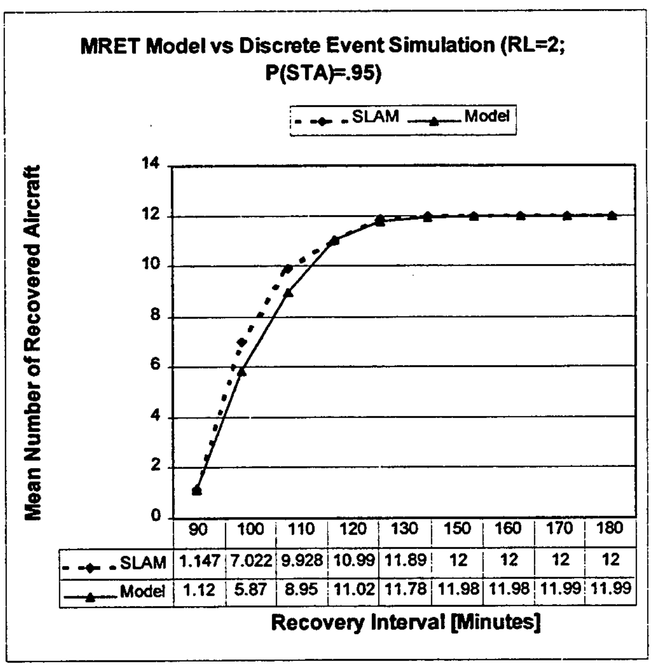


Figure 5-8. Comparison of Mean Number of Recovered Aircraft for RL=2 and P(STA)=0.95

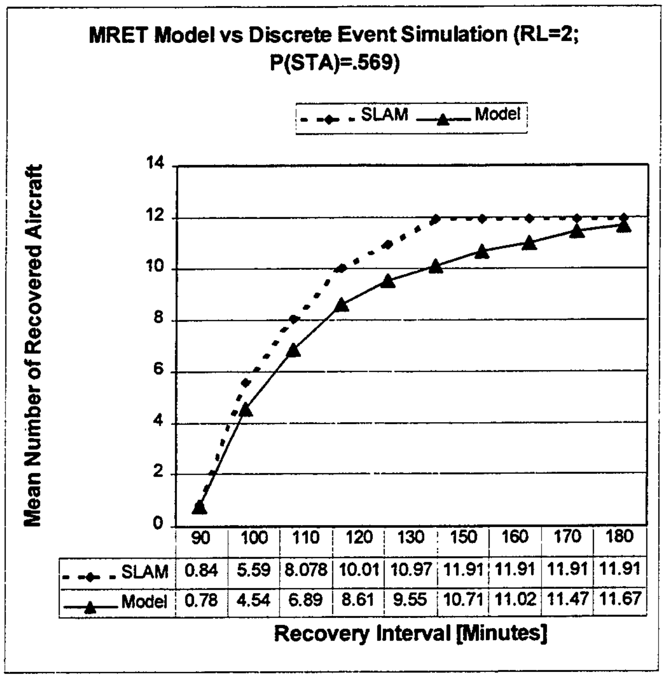


Figure 5-9. Comparison of Mean Number of Recovered Aircraft for RL=2 and P(STA)=0.569

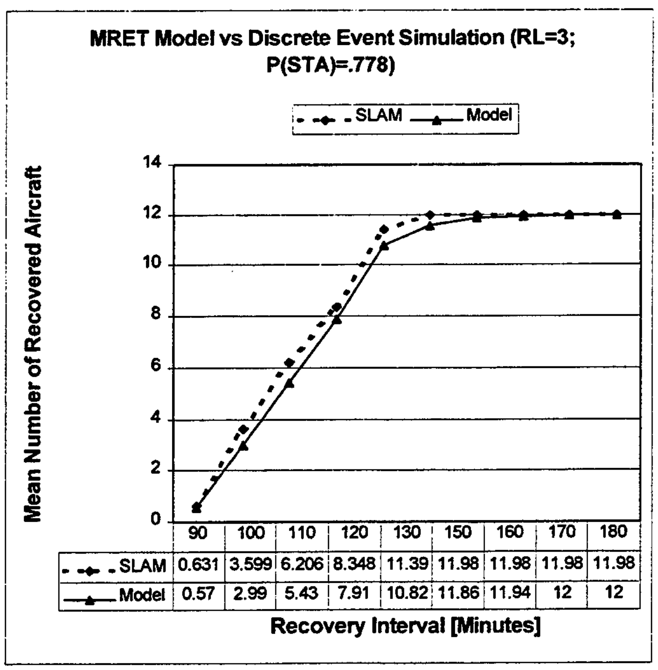


Figure 5-10. Comparison of Mean Number of Recovered Aircraft for RL=1 and P(STA)=0.778

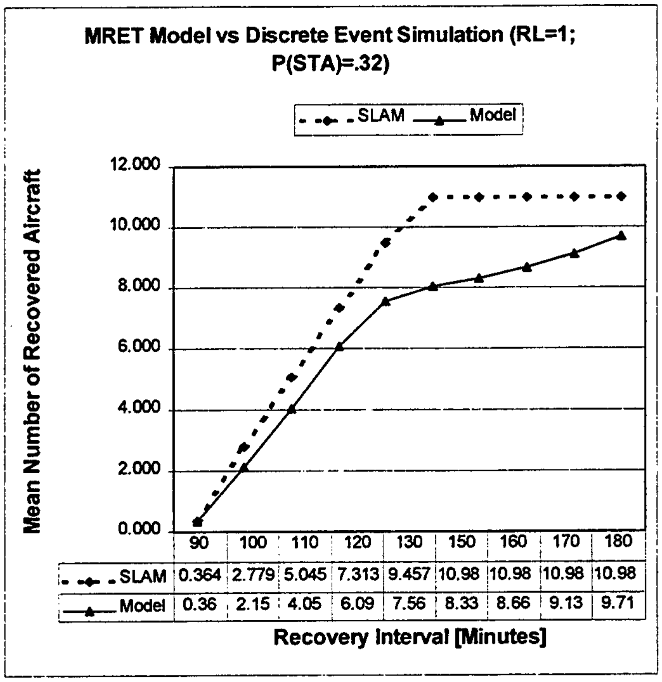


Figure 5-11. Comparison of Mean Number of Recovered Aircraft for RL=1 and P(STA)=0.32

General Conclusions about Mean Number of Recovered Aircraft. From Figures 5-6 through 5-11, the MRET and the SLAM II model tend to behave in a similar manner for all resource availability and unscheduled maintenance actions demand considered in this experiment. For each resource level, when the probability of obtaining resources at site is high (high P(STA) value) the concordance between the two models is very good. The MRET behaves in a pessimistic (conservative) manner. Note that the compared values are point estimates; they are means obtained via two dissimilar descriptive modeling techniques. To establish the statistical significance of differences between the point estimates, the null hypothesis that the distributions of the number of recovered aircraft were identical was established, and 95% confidence intervals for the mean computed by each model compared. In all cases the null hypothesis was rejected --the differences are statistically significant at α=0.05. In practical terms those differences

were found to be less conclusive. If we accept that for operational planning purposes fractional aircraft have no practical meaning and that, adopting a risk adverse behavior, decision makers would round down the model response, then the maximum practical difference observable with this experiment was 1 aircraft at resources level 3 and 2 aircraft at resource levels 2 and 1. The greater divergence between the models was always observed for high-demand situations.

Chapter Summary

This chapter presented the results obtained during the MRET verification process. Special input test and response reasonableness tests were first performed. Finally, a comparison between the results of the MRET versus a SLAM II program simulating the same logic was performed.

It was found that the MRET performs as was reasonable and predicted. In addition, the MRET and the SLAM II model tend to behave in a similar manner for all resource availability and unscheduled maintenance action demand considered in this experiment. The MRET behaves in a pessimistic (conservative) manner. The greater divergence between the models was always observed for high-demand situations.

The next chapter will present a summary of the finding of this research, final conclusions, and suggestions for future research

VI. Conclusions

Introduction

This final chapter synthesizes all the information presented in the previous chapters. It summarizes the findings, answers the research questions, discusses conclusions and suggests areas for further research.

Research Findings

The research findings are presented in connection with the investigative question that led towards them.

What variables must be used to link the model to the operational plan and to the overall logistics plan?

An important first finding is that this investigative question itself is too narrow to capture all the linkages necessary to define in a complete model. Validated comprehensive models are linked both to aspects of mission accomplishment that are controllable by operations and logistics decision makers and uncontrollable aspects such as weather conditions and enemy action.

A second finding is that most of the models, except for the most complex ones, tend to restrict the consideration of maintenance resources to a small but highly consistent group. Manpower, spare parts, and support equipment constitute this top-priority collection of resources (which also were deemed highly important by the AAF logistics decision-makers).

As a third finding, we can say that the 30 conceptual variables that were consolidated during this research (which are detailed in Table 3-1), while not a completely exhaustive list, were found to provide linkages to the operational plan, logistics plan, and uncontrolled events such us meteorological conditions and enemy action. Table 3-2 presents the conceptual variables that were detected as more important for modeling the effect of different policies, postures or events.

The second research question was stated in the following terms:

What is the most appropriate type of model to apply considering uncertainty and risk assessment?

In order to increase the chance of model acceptance, its contribution to the manager's analysis-education-decision was established as a high priority goal. Model completeness, together with high response speed were identified as key model success factor. To model a scenario characterized by dynamism, uncertainty and complexity, simulation was found to be the most appropriate mathematical tool. Furthermore, the decision of implementing the model on a spreadsheet imposed additional restrictions that were taken into consideration during the selection of the modeling strategy.

The following combination of modeling strategies where chosen because of their potential to satisfy the condition derived from the goal, key success factors, the scenario and the selected software:

- *Main Modeling strategy*: Monte Carlo simulation was selected to attain an acceptable degree of completeness while facilitating its implementation on a spreadsheet platform.

- *Auxiliary Modeling Strategy*: a combination of deterministic, functional probabilistic and heuristic methods was chosen to deliver concrete and high-speed responses, enhancing the manager's analysis-education-decision process.

The third question was:

What is the sensitivity of the results yielded by the model to variations in the underlying assumptions?

The MRET was not externally validated during this research. However, verification and validation actions were accomplished as part of the model's development process, and this investigative question was addressed during this procedure. After a reasonable level of confidence on the model's behavior was attained via debugging, special input testing and response reasonableness tests, its results were contrasted against a model that follows the same logic but built using dynamic discrete-event simulation. This experiment isolated the effect of the closed solution formula (which constitutes the functional probabilistic and heuristic part of the model that was introduced during this research). The design of the experiment also examined the effect of assuming a lognormal distribution for down time due to unscheduled repairs. The idea here was to compare the results of the MRET against a dynamic simulation that models the same logic using a validated methodological approach. The goal of the experiment was to assess the difference (error) between both models and simultaneously evaluate the sensitivity of this error to what was found to be a critical condition for models that use a functional probabilistic approach. This condition is the workload imposed on the system, which increases as resource availability decreases and maintenance action demand

increases. Again it is important to stress that this procedure does not seek to externally validate the model.

As a first general finding we can state that the results of MRET are very close to those obtained via dynamic discrete event simulation. The second finding is that as the workload on the system increases, the divergence between the two models' results tends to increase. This behavior is similar to what was already reported for the results from functional probabilistic models versus dynamic discrete-event simulation.

When computing down time due to unscheduled repair actions, the MRET's combined functional probabilistic and heuristics approach tends to perform reasonably well (+/- 5% error) at moderate or high level of resources availability and low demand (up to 0.8 probability of obtaining resources at site). As the demand for unscheduled maintenance tasks increases, the probability of obtaining resources at site decreases and the divergence of results tend to increase. When the level of resource falls to a minimum this approach tends to yield optimistic results (i.e., the mean and standard deviation fall below the dynamic simulation results. The standard deviation deteriorates the most, while the mean tends to remain similar to the dynamic simulation results.

The mean recovery time obtained by the MRET is very close to the one yielded by dynamic simulation for a wide range of level of resources and unscheduled maintenance action demands. The mean of recovery time shows a low sensitivity to the errors found for the down time distribution. The standard deviation error appears more sensitive to the resource levels and demand of maintenance actions. At high or moderate resources levels, the errors are positive, while at low levels they become negative. As the maintenance action demands increase the divergence of results tend to increase. A

possible explanation for this phenomenon is that the lognormal distribution assumed for down time (which is skewed to the right for the shape parameters that were observed during the experiment (approximately 0.24)) is increasing the variability of the Monte Carlo simulation results.

When computing the mean expected number of aircraft to be recovered in a given time interval, we compared two combinations of techniques: the MRET's Monte Carlo simulation combined with a functional-probabilistic-heuristics approach, versus a dynamic simulation. The MRET and the SLAM II model tend to behave in a comparable manner across all the spectrum of resource availability and unscheduled maintenance action demands that were considered in this experiment. For each resource level, when the demand of maintenance action is low, the concordance between the two models is very good. The MRET behaves always in a pessimistic (conservative) manner. Although always statistically significant, in practical terms the differences were found to be less conclusive. In the worst case the practical difference was -2 aircraft; an assessment of the impact of this discrepancy can only be done within the context of the criticality of the affected missions. The greater divergence between the models was always observed in high-demand situations.

The fourth investigative question was:

What data must be contained in the logistics databases to satisfy the needs of the model?

To satisfy the information needs for the MRET (as detailed in Chapter 4), the following data must be available (further details about the definition of these data needs can also be found in Chapter 4):

- For each critical failure mode: Mean Time between Failures (MTBF), resources needed to repair the failures, and associated repair time distributions;
- Scheduled (mandatory) maintenance activities to generate a sortie and their accomplishment time distribution, for each defined set of resources;
- Incompatibilities that preclude simultaneous scheduled task accomplishment;
- Maintenance resource transit time distributions for the different maintenance sites.

To enable future model improvements, it would be useful that the following information is also available:

- Mission abort rate. This parameter may be used to correct the model output, in order to account for failures that are discovered after the aircraft was recovered, but prior to its take off;
- Historic information about actual time to perform scheduled and unscheduled maintenance tasks.

General Conclusion

This thesis has identified a different mathematical model to address the problem of maintenance capacity necessary to support a given level of operational activity. The degree of model development reached in this work can be assessed as a concept exploration. The prototyping approach selected for the MRET's development has led to a model of a model, which yielded results during the verification process that were found to be reasonable. When results are compared to a model built using a validated

methodology and same logic, the MRET behaves in a comparable manner, which was found to be always conservative. Although the two models' results diverged consistently for cases of scarce resource availability combined with high demands for maintenance actions, the practical significance of that divergence must be judged according to the model's intended use and the mission criticality.

During its verification, the MRET shows a conservative tendency. If future validation efforts confirm this trend, then caution must be exercised while interpreting its results. For example, if the model is used to support trade studies that define an optimum of resources to be acquired, then the MRET may overstate required amounts due to its conservative nature. On the other hand, if the MRET is used as a decision support system to determine the feasibility of a defined operational activity for a given amount of resources, the same conservative nature of the model will tend to understate the number of aircraft that the system is actually capable of recovering in a given interval.

In the opinion of this author, enough evidence was gathered about the MRET's response behavior to conclude that it is worthwhile to go on with the next phase in its development --validation of its results within the AAF environment. The organization will have to commit resources to support the validation effort, but the expected payoff is a robust logistics model that can run on existing hardware and software. If the MRET were found invalid or its operational version programmed on spreadsheet were found unable to manage the complete size of the problem, at least an improved understanding of the logistics process itself and a thorough insight on what a logistic model suitable for the AFF should do will be attained.

Areas for Further Research

At least three areas for further research are possible:

- *Model Validation.* At this point, it is clear that model validation is the most crucial area that is left to be done. Validation will determine whether the modeling approach used in this thesis is appropriate to model the proposed scenario within the AAF environment. This work must include the validation of both inputs and the MRET's assumptions using actual system data as the basis for comparison.
- *Improvement of Heuristics for Approximating AND Node Response*: For the MRET, a heuristic was developed using a particular approach and simulation results within a range of arbitrarily established transit times. Although those transit times are thought to be reasonable values, when a representative set of data depicting the particular environment of the AAF is obtained, a new approximating formula using the same or different approach may need to be set up and tuned.
- *Stability of the Spreadsheet Software and Time Need to Compute the Model when a Complete Scenario Is Modeled.* Currently, the MRET supports only 10 critical failure modes (each requiring one part and three other resources -- personnel, test equipment and support equipment). The performance of a spreadsheet program that manages all the data needed to model an actual deployment scenario must be determined.

APPENDIX A

Logistics Models Analysis

Fork-Join Queuing Network

Objectives: (1) Steady-state sortie generation rate

This model follows an algorithm strategy and applies mean value analysis of a network of queues in an iterative way. The model calculates the steady-state performance in terms of sortie rate and resource utilization.

Table A-1. Fork-Join Queuing Network Analysis

#	Variables		Resources	Mx Tasks	Mx Leves
	Clas s	Concept			
1	AD	Prob. of mission abort	Not specified	Mun. upload	Flight line
2	AD	Reliability parameters		Repair	
3	AD	Repair time distributions(Exp.)		Taxi	
4	OP	Number of aircraft		Troubleshooting	
5				Turn around	

Base Operations-Maintenance Simulator (BOMS)

Objectives: (1) Policy test

This model simulates the essential characteristics of an Air Force Base (SAC B-52/KC-135).

Table A-2. Base Operations-Maintenance Simulator (BOMS) Analysis

#	Variables		Resources	Mx Tasks	Mx Leves
	Class	Concept			
1	AD	Failure Criticality	AGE	Unscheduled Mx	Flight line
2	AD	Repair time distributions	Personnel	Mun. download	Base
3	AD	Resource required	Spare parts	Mun. upload	
4	MP	Mx task priority		Postflight	
5	MP	Personnel skills		Preflight	
6	MP	Resource dispath criterion		Servicing	
7	MP	Workshift policy			
8	OP	Aircraft Type			
9	OP	Cancellation criterion			
10	OP	Mission Type			
11	OP	Number of aircraft			
12	OP	Sortie length			
13	OP	Take-off time			
14	SP	Aircraft Cannibalization policy			
15	SP	Availability of resources			
16	SP	Depot Resupply			
17	SP	Substitutability			

Logistics Composite Model (LCOM)

Objectives: (1) Logistics requirements studies
(2) Op. Req. / Preferred resource mix

A model for simulating overall operations and support functions at an Air Force Base. It is applicable to a variety of planning studies concerned with base level functions. It can be used in the requirement studies in support of contingency deployment and determination of preferred repair policies, as well as resources requirement studies for weapon being designed. It may also be applied in any problem involving appreciable interaction among the many functions accomplished at an Air Force Base.

Table A-3. Logistics Composite Model (LCOM) Analysis

#	Variables		Resources	Mx Tasks	Mx Leves
	Class	Concept			
1	AD	Reliability parameters	AGE	Debriefing	Flight line
2	AD	Repair time distributions	Personnel	Periodic inspections	Shop repair
3	AD	Resource required	Spare parts	Supply	
4	MP	Aircraft Cannibalization policy		Troubleshooting	
5	MP	Expedite repair		Unscheduled Mx	
6	MP	Mx task priority			
7	MP	Overtime			
8	MP	Resource cost			
9	MP	Task network			
10	MP	Work-in-proces preemption			
11	MP	Workshift policy			
12	OP	Cancellation criterion			
13	OP	Mission Type			
14	OP	Number of aircraft			
15	OP	Sortie length			
16	OP	Take-off time			
17	SP	Resource authorized quantity			
18	SP	Substitutability			

Planned Logistics Analysis and Evaluation Technique (PLANET)

Objectives: (1) Hardware/Operations./Logistics Studies

Simulation model that is able to examine interactions among aircraft design, operations and logistics support of various weapon systems in a single or multi base scenario. Design to help managers understand the operation of the systems and find a rationale for effective and efficient resource allocation

Table A-4. Planned Logistics Analysis and Evaluation Technique (PLANET) Analysis

#	Variables		Resources	Mx Tasks	Mx Leves
	Class	Concept			
1	E	Whether-dependet transit times	AGE	Modification	Flight line
2	AD	Hardware definition	Personnel	Periodic inspections	Base
3	AD	Reliability parameters	Spare parts	Postflight	Depot
4	AD	Repair time distributions		Travel to site	
5	AD	Resource required		Unscheduled Mx	
6	MP	Resource dispath criterion			
7	MP	Workshift policy			
8	OP	Dispersion			
9	OP	Randon generated Op. Data			
10	SL	AGE periodic servicing			
11	SP	Availability of resources			

Support-Availability Multi-System Operations Model (SAMSON)

Objectives: (1) Resource Mix / Op. Capability
(2) Op. Req. / Preferred resource mix

This model simulates weapon system and logistics support events at one or more bases during peace or wartime. Helps estimate unit capability and limitations to meet selected operations objectives.

Table A-5. Support-Availability Multi-System Operations Model (SAMSON)

#	Variables		Resources	Mx Tasks	Mx Leves
	Class	Concept			
1	EA	Battle damage index	AGE	Debriefing	Flight line
2	EA	Combat losses index	Facilities	Fueling	
3	AD	Failure Criticality	Personnel	Ground Failure	
4	AD	Max simult. Number of Mx. Personnel	Spare parts	Launch service	
5	AD	Prob. of mission abort		Mun. download	
6	AD	Reliability parameters		Mun. upload	
7	AD	Repair time distributions		Periodic inspections	
8	MP	Cross training		Unscheduled Mx	
9	MP	Inspection schedule			
10	MP	Personnel skills			
11	MP	Task incompatibility			
12	OP	Alert schedule			
13	OP	Cancellation criterion			
14	OP	Dispersion			
15	OP	Number of aircraft			
16	OP	Sortie length			
17	OP	Take-off time			
18	SL	AGE Mx delay			
19	SL	Facility Mx delay			
20	SP	Availability of resources			
21	SP	Depot Resupply			

Theater Simulation of Airbase Resources (TSAR)

<u>Objectives:</u> (1) Policy tests.(operational, maintenance, supply)

Simulation that analyzes interactions among on-base resources and air base capability to generate aircraft sorties in dynamic, rapidly evolving wartime environments.

Table A-6. Theater Simulation of Airbase Resources (TSAR)

#	Variables		Resources	Mx Tasks	Mx Leves
	Class	Concept			
1	E	Minimum weather condition (mission)	AGE	Fueling	Flight line
2	EA	Simulated battle damage	Facilities	Gun reload	Base
3	EA	Simulated Combat Losses	Munition	Inspect	Theater
4	AD	Alternative resource requirement	Personnel	Land/taxi	CONUS
5	AD	Reliability parameters	POL	Mun assembly	
6	AD	Repair time distributions	Spare parts	Mun. download	
7	MP	Cross training	TRAP	Mun. upload	
8	MP	Expedite repair		Reconfiguration	
9	MP	Mx task priority		Shelter	
10	MP	Personnel skills		Taxi/launch	
11	MP	Resource required		Unscheduled Mx	
12	MP	Shop repair priority			
13	MP	Task incompatibility			
14	MP	Task network			
15	MP	Work-in-proces preemption			
16	MP	Workshift policy			
17	OP	Aircraft Type			
18	OP	Dispersion			
19	OP	Max/Min air unit size			
20	OP	Mission priority			
21	OP	Number of aircraft			
22	OP	Prob. of retaining munition			
23	OP	Required Munition			
24	OP	Sortie length			
25	OP	Take-off time			
26	OP	Alert schedule			
27	SP	Aircraft Cannibalization policy			
28	SP	Availability of resources			
29	SP	Depot resupply			
30	SP	Lateral resupply			
31	SP	LRU cannibalization policy			
32	SP	CONUS resupply			

APPENDIX B

Conceptual Variables: Observed Frequency of Use

Table B-1. Variables That Were Identified During Logistics Models Review (Part 1 of 2)

Number	Variable Group	Conceptual Variable
1	AD	Alternative resource requirement
2	AD	Failure criticality
3	AD	Hardware definition
4	AD	Max simultaneous number of Mx. Personnel
5	AD	Probability of mission abort
6	AD	Reliability parameters
7	AD	Repair time distributions
8	AD	Resource required
9	E	Minimum weather condition (mission)
10	E	Whether-dependent transit times
11	EA	Battle damage index
12	EA	Combat losses index
13	EA	Simulated battle damage
14	EA	Simulated combat losses
15	MP	Cross training
16	MP	Expedite repair
17	MP	Inspection schedule
18	MP	Mx task priority
19	MP	Overtime
20	MP	Personnel skills
21	MP	Resource cost
22	MP	Resource dispatch criterion
23	MP	Shop repair priority
24	MP	Task incompatibility
25	MP	Task network
26	MP	Work-in-process preemption
27	MP	Workshift policy
28	OP	Aircraft type
29	OP	Alert schedule

Table B-1. Variables That Were Identified During Logistics Models Review (Part 2 of 2)

Number	Variable Group	Conceptual Variable
30	OP	Cancellation criterion
31	OP	Dispersion
32	OP	Max/Min air unit size
33	OP	Mission priority
34	OP	Mission Type
35	OP	Number of aircraft
36	OP	Probability of retaining munitions
37	OP	Random generated Operational Data
38	OP	Required Munitions
39	OP	Sortie length
40	OP	Take-off time
41	SL	AGE Mx. delay
42	SL	AGE periodic servicing
43	SL	Facility Mx. delay
44	SP	Aircraft cannibalization policy
45	SP	Availability of resources
46	SP	Depot resupply
47	SP	Lateral resupply
48	SP	LRU cannibalization policy
49	SP	Resource authorized quantity
50	SP	Substitutability
51	SP	CONUS resupply

Aircraft Design Conceptual Variable

Table B-2. Aircraft Design Conceptual Variable per Model

Item Number	Variables	FJQN	BOMS	LCOM	PLANET	SAMSON	TSAR	Frequency
		MODELS						
1	Repair time distributions	1	1	1	1	1	1	6
2	Reliability parameters	1		1	1	1	1	5
3	Resource required		1	1	1			3
4	Failure Criticality		1			1		2
5	Prob. of mission abort	1				1		2
6	Alternative resource requirement						1	1
7	Hardware definition				1			1
8	Max simult. No. of Mx. Personnel					1		1
	Total	3	3	3	4	5	3	

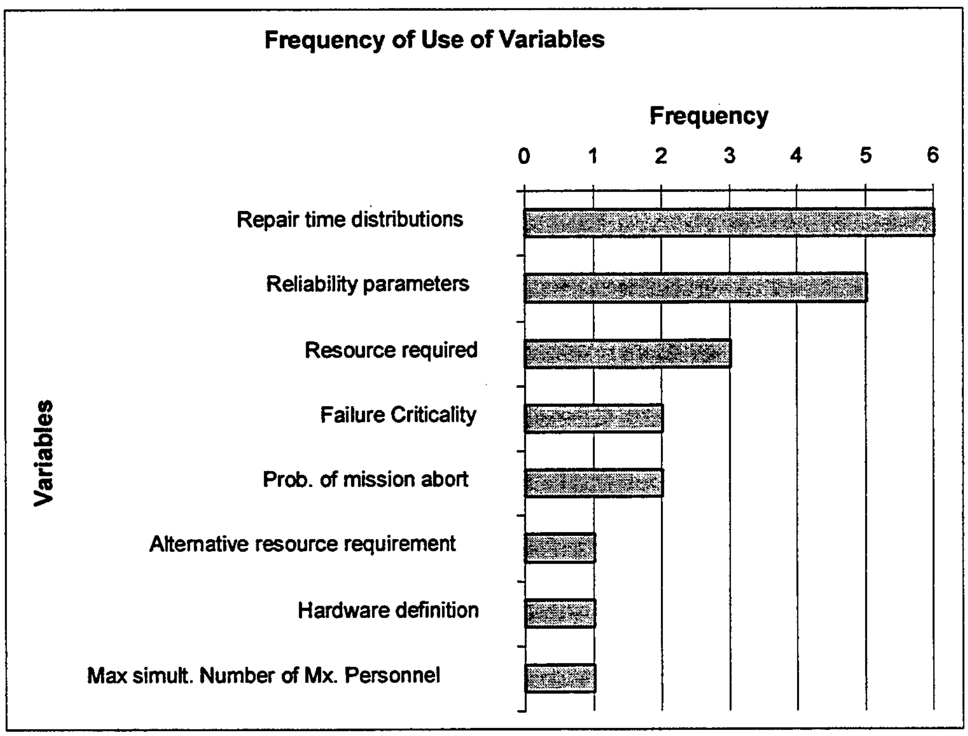


Figure B-1. Aircraft Design Conceptual Frequency of Use

Operational Policy Conceptual Variables

Table B-3. Operational Policy Conceptual Variables per Model

Item Number	Variables	FJQN	BOMS	LCOM	PLANET	SAMSON	TSAR	Frequency
		Models						
1	Number of aircraft	1	1	1		1	1	5
2	Sortie length		1	1		1	1	4
3	Take-off time		1	1		1	1	4
4	Cancellation criterion		1	1		1		3
5	Dispersion				1	1	1	3
6	Aircraft Type		1				1	2
7	Mission Type		1	1				2
8	Alert schedule					1	1	2
9	Max/Min air unit size						1	1
10	Mission priority						1	1
11	Prob. of retaining munition						1	1
12	Randon generated Op. Data				1			1
13	Required Munition						1	1
	Total	1	6	5	2	6	10	

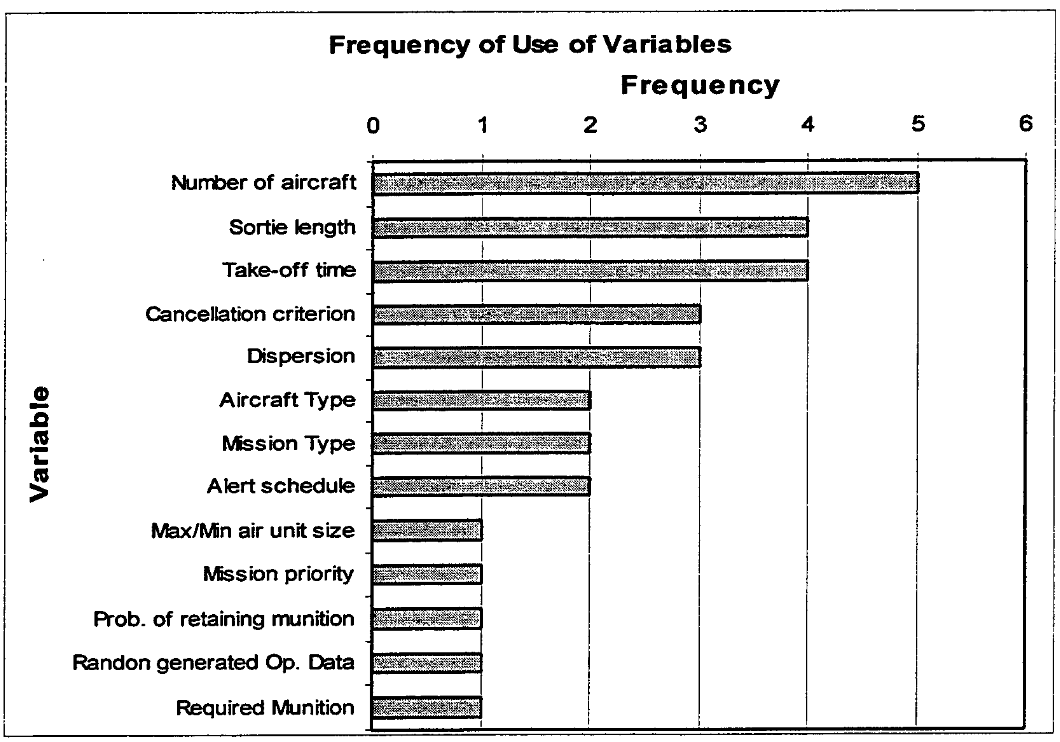


Figure B-2. Operational Policy Conceptual Variable Frequency of Use

Maintenance Policy Conceptual Variables

Table B-4. Maintenance Policy Conceptual Variables per Model

Item Number	Variables	FJQN	BOMS	LCOM	PLANET	SAMSON	TSAR	Frequency
		MODELS						
1	Workshift policy		1	1	1		1	4
2	Mx task priority		1	1			1	3
3	Personnel skills		1			1	1	3
4	Cross training					1	1	2
5	Expedite repair			1			1	2
6	Resource dispath criterion		1		1			2
7	Task incompatibility					1	1	2
8	Task network			1			1	2
9	Work-in-proces preemption			1			1	2
10	Aircraft Cannibalization policy			1				1
11	Inspection schedule					1		1
12	Overtime			1				1
13	Resource cost			1				1
14	Resource required						1	1
15	Shop repair priority						1	1
	Total	0	4	8	2	4	10	

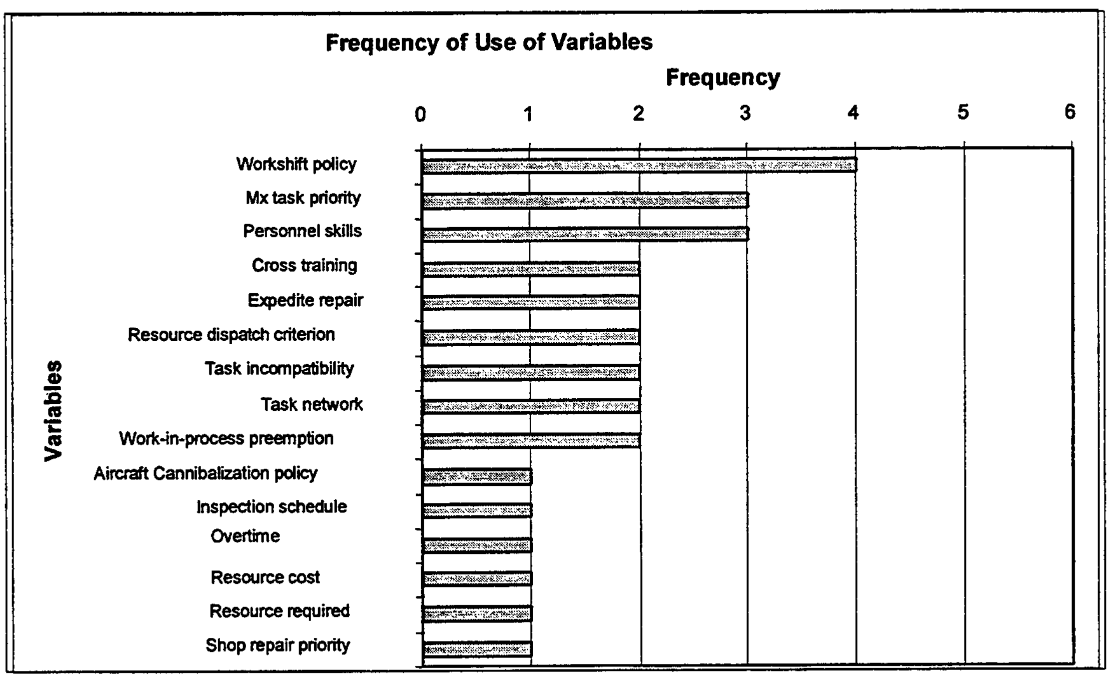


Figure B-3. Maintenance Policy Conceptual Variable Frequency of Use

Secondary Logistics Conceptual Variables

Table B-5. Secondary Logistics Conceptual Variables per Model

Item Number	Variables	FJQN	BOMS	LCOM	PLANET	SAMSON	TSAR	Frequency
		Models						
1	AGE Mx delay					1		1
2	AGE periodic servicing				1			1
3	Facility Mx delay					1		1
	Total	0	0	0	1	2	0	

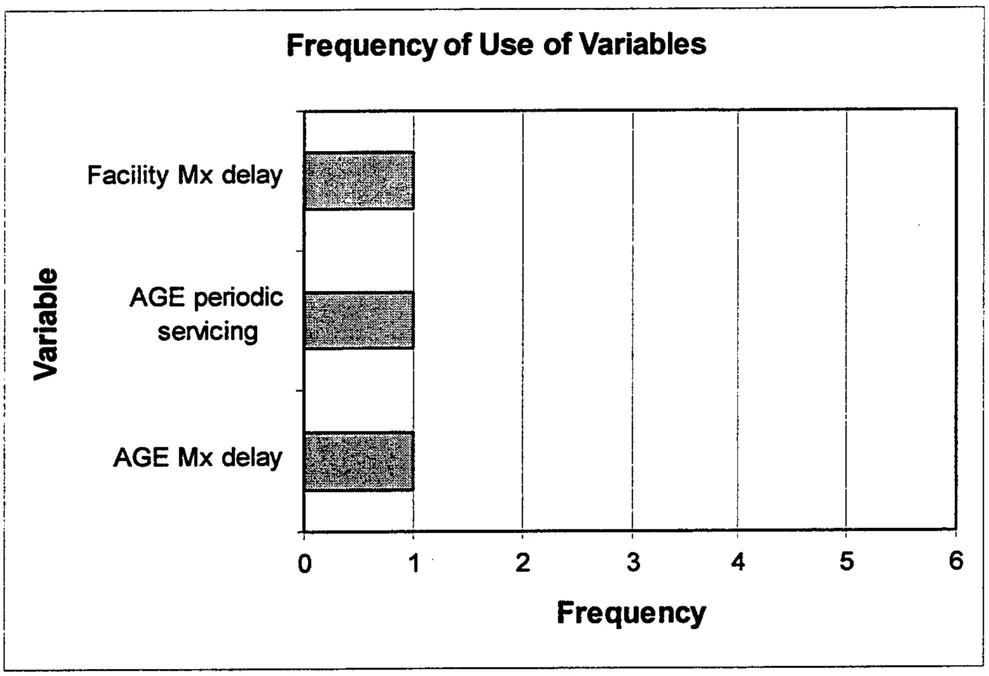


Figure B-4. Secondary Logistics Conceptual Variable Frequency of Use

Environmental Conceptual Variables

Table B-6: Environmental Conceptual Variables per Model

Item Number	Variables	FJQN	BOMS	LCOM	PLANET	SAMSON	TSAR	Frequency
		MODELS						
1	Minimum weather condition (mission)						1	1
2	Whether-dependet transit times				1			1
	Total	0	0	0	1	0	1	

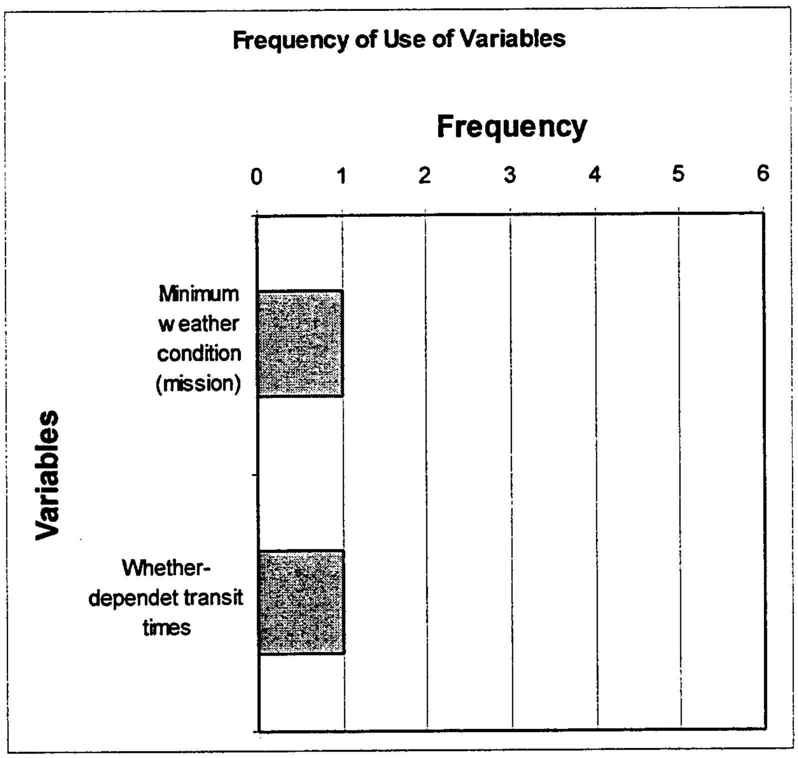


Figure B-5. Environmental Conceptual Variable Frequency of Use

Enemy Action Conceptual Variables

Table B-7. Enemy Action Conceptual Variables per Model

Item Number	Variables	FJQN	BOMS	LCOM	PLANET	SAMSON	TSAR	Frequency
		MODELS						
1	Battle damage index					1		1
2	Combat losses index					1		1
3	Simulated battle damage						1	1
4	Simulated Combat Losses						1	1
	Total	0	0	0	0	2	2	

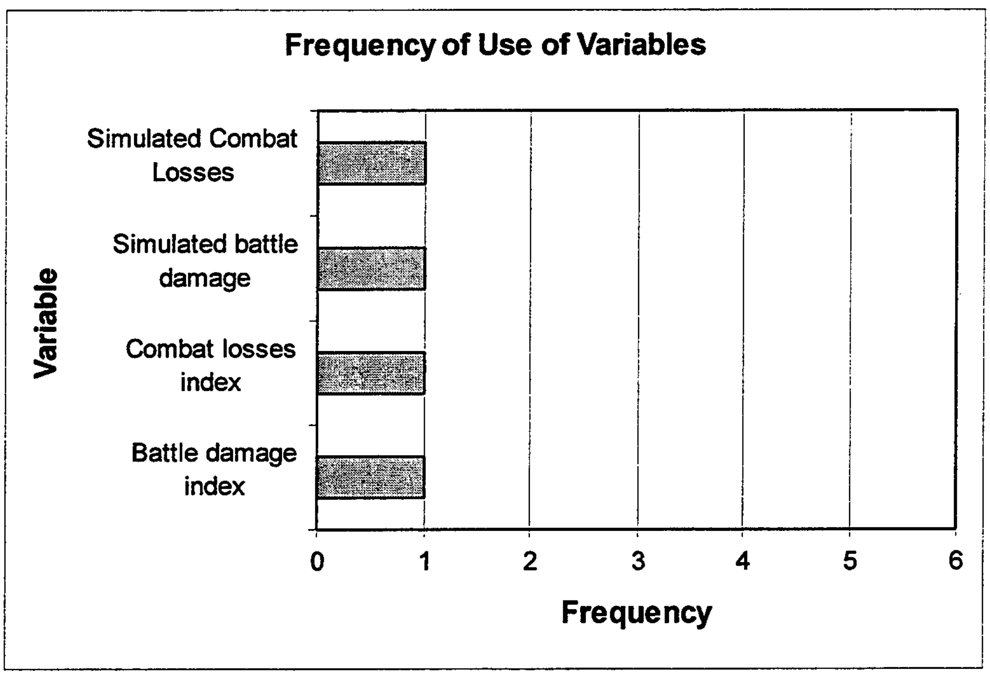


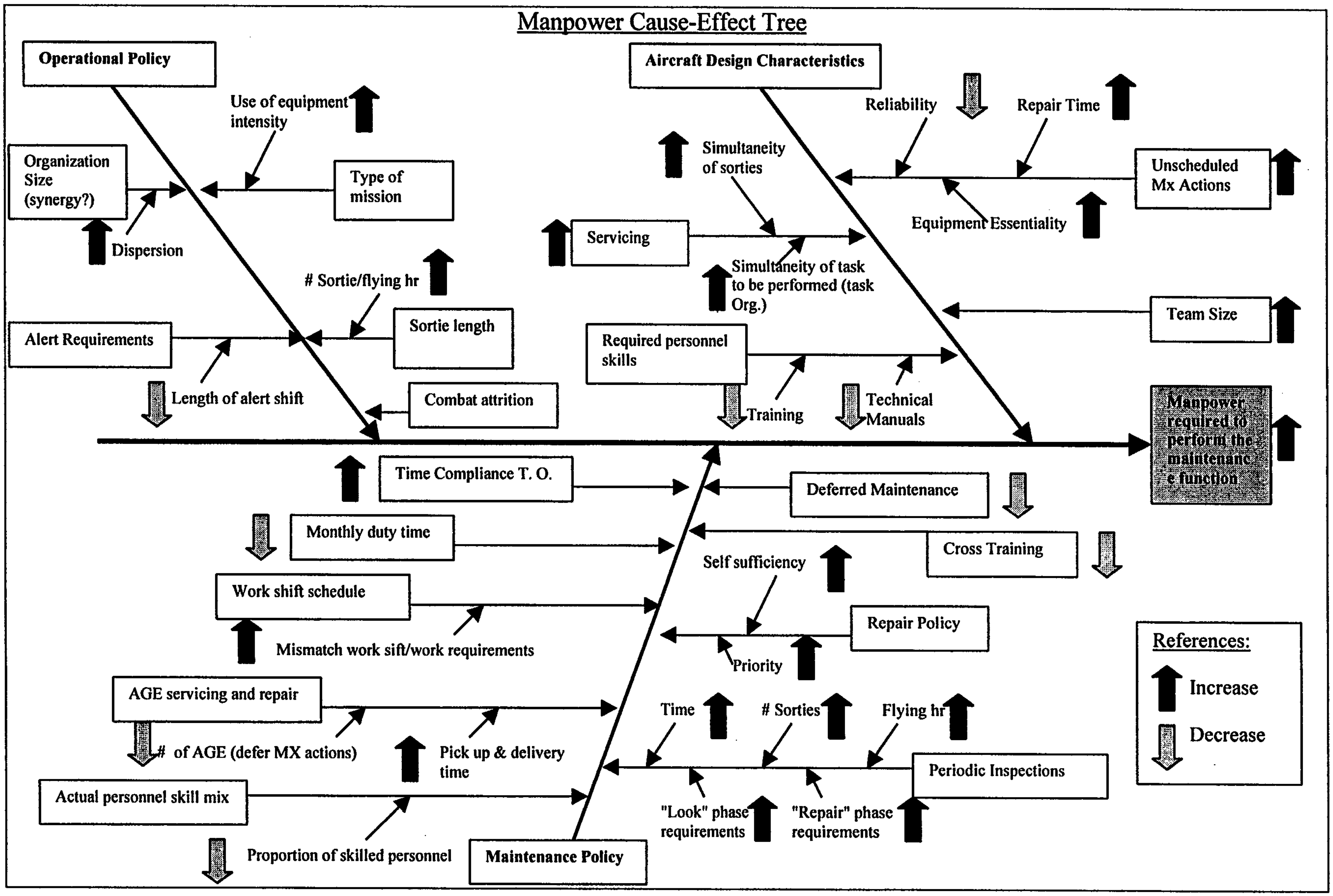
Figure B-6. Enemy Action Conceptual Variable Frequency of Use

APPENDIX C

Conceptual Variable Confirmation Study

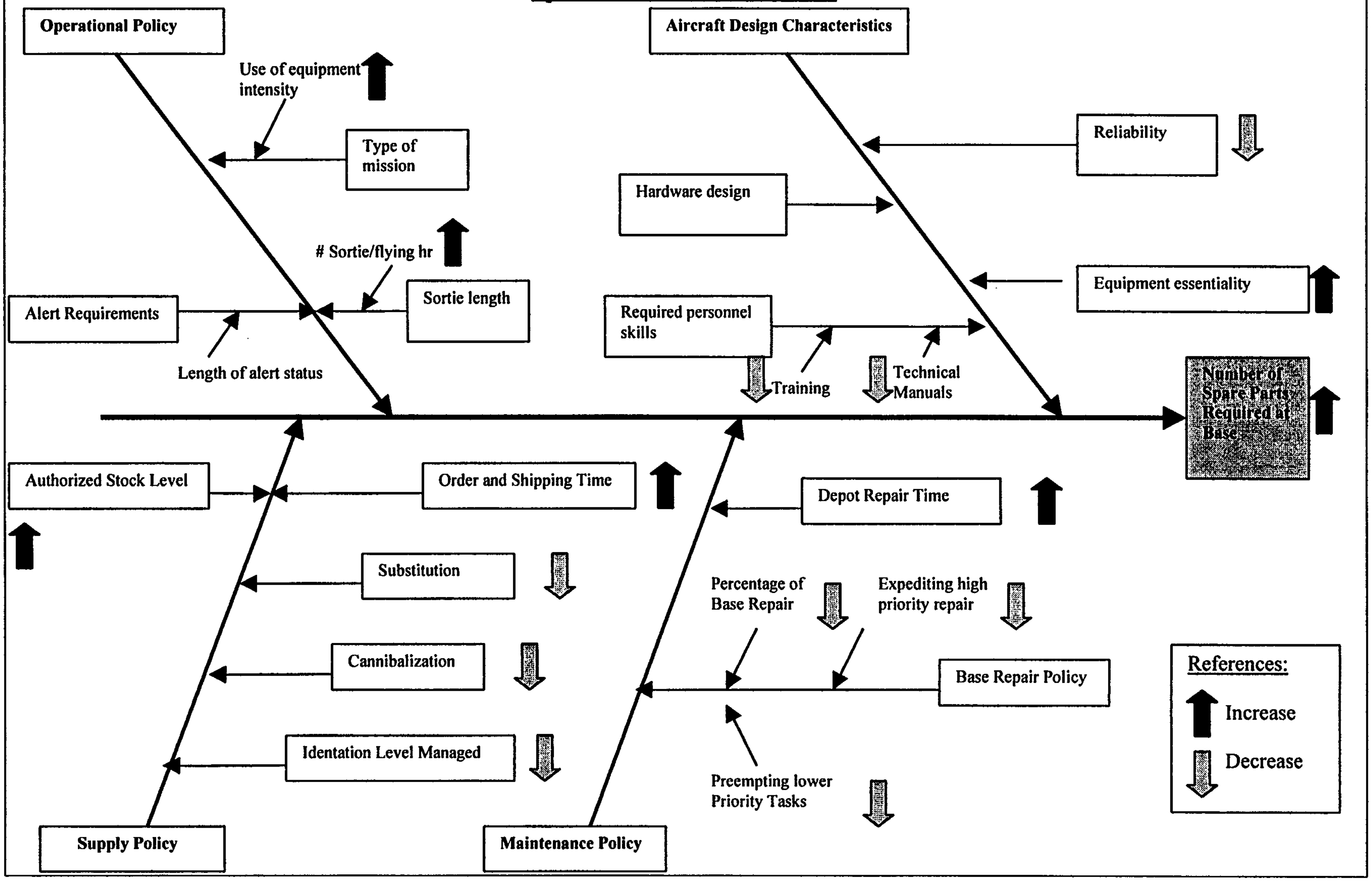
Table C-1. Maintenance Resources: Observed frequency of Use

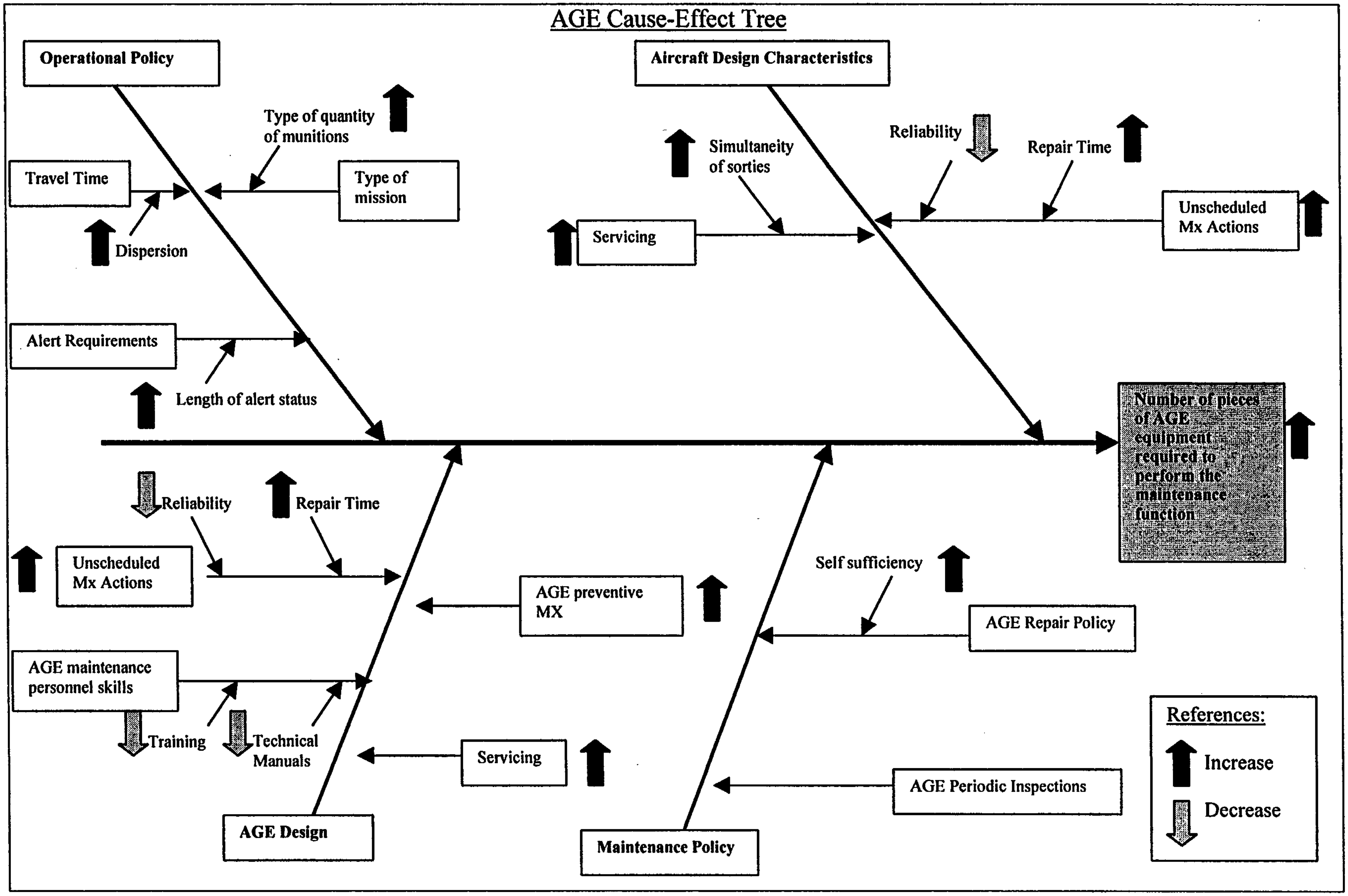
Resource	Logistics Models					
Computed	BOMS	LCOM	PLANET	SAMSON	TSAR	SUM
AGE	1	1	1	1	1	5
Facilities				1	1	2
Munitions					1	1
Personnel	1	1	1	1	1	5
POL					1	1
Spare Parts	1	1	1	1	1	5
TRAP					1	1



Manpower Cause-Effect Tree
Operational Policy
Use of equipment intensity
Organization Size (synergy?)
Type of mission
Dispersion
Sortie/flying hr
Alert Requirements
Sortie length
Length of alert shift
Combat attrition
Aircraft Design Characteristics
Reliability
Repair Time
Simultaneity of sorties
Unscheduled Mx Actions
Equipment Essentiality
Servicing
Simultaneity of task to be performed (task Org.)
Team Size
Required personnel skills
Training
Technical Manuals
Manpower required to perform the maintenanc e function
Time Compliance T. O.
Deferred Maintenance
Monthly duty time
Cross Training
Self sufficiency
Work shift schedule
Repair Policy
Mismatch work sift/work requirements
Priority
AGE servicing and repair
Time
Sorties
Flying hr
# of AGE (defer MX actions)
Pick up & delivery time
Periodic Inspections
Actual personnel skill mix
"Look" phase requirements
"Repair" phase requirements
Proportion of skilled personnel
Maintenance Policy
References:
Increase
Decrease

Spare Parts Cause-Effect Tree





AGE Cause-Effect Tree
Operational Policy
Type of quantity of munitions
Travel Time
Type of mission
Dispersion
Alert Requirements
Length of alert status
Aircraft Design Characteristics
Simultaneity of sorties
Reliability
Repair Time
Servicing
Unscheduled Mx Actions
Number of pieces of AGE equipment required to perform the maintenance function
Reliability
Repair Time
Unscheduled Mx Actions
AGE preventive MX
AGE maintenance personnel skills
Training
Technical Manuals
Servicing
AGE Design
Self sufficiency
AGE Repair Policy
AGE Periodic Inspections
Maintenance Policy
References:
Increase
Decrease

APPENDIX D

Survey Instrument

Maintenance Resource Computation Model

Survey

Introduction

In partial fulfillment of a master's degree program, I have chosen to develop a spreadsheet logistics model to compute the type and quantity of maintenance resources needed to support the activity of a deployed air unit.

After reviewing information concerning several models developed within the United States Department of Defense (DOD) environment, I have gathered enough data to reach a comprehensive understanding of inputs that are usually used to operate these models, types of resources that are computed, as well as the desirable characteristics that these models should have in order to be an effective help for logistics decision makers. This information, although conceptually applicable to any aircraft deployment situation, is treated according to the priorities that emerge from DoD needs.

In this stage of my research I need to order the relative importance of these data consistently with the particular scenario the Argentine Air Force is involved in. This will allow me to select the most relevant aspects of the problem that are feasible to include in

the initial model, while providing for enough flexibility to incorporate more features in future evolutions.

Survey Purpose

The purpose of this survey is to request your opinion about desirable model characteristics, resources to be computed and important variables to include.

Survey General Structure

This survey is comprised of four parts. First, there is an administrative part, which is intended to record information about the respondent. Part I deals with the desired characteristics of an effective model; Part II is related to resources; Part III refers to input variables.

Content of this document

To facilitate the execution of the survey the content of the document has been divided into the following six independent parts attached as attachments:

(1) Attachment 1 contains supplementary information about the background, objective and scope of the project.

(2) Attachment 2 includes instructions to perform Part I of the survey

(3) Attachment 3 includes instructions to perform Part II of the survey

(4) Attachment 4 includes instructions to perform Part III of the survey.

(5) Attachment 5 contains a glossary defining selected terms (they are indicated with superscript numbers).

(6) Attachment 6 includes the form to respond this survey.

Response return procedure

Attachment 6 with your responses can be sent me back to the following addresses, in which I also will be available to give you more information in case you need it:

(1) E-mail: JFGUAR@aol.com.

(2) FAX : (937) 667-9418

It is important for the timely accomplishment of my project that you send your response by November 28, 1998.

ATTACHMENT 1

Research Background

Introduction

The Argentine Air Force (AAF) has undertaken the task of reviewing its logistics doctrine with the aim of supporting its mission on the basis of better-designed structure of resources. In this regard, a new Logistics Regulation coded as RAC 9 was issued in 1997. This document emphasizes the importance of adequate sizing of logistics support, establishing the necessity of planning Logistics Units of Deployment (LUD) (RAC 9, 1997:22-23). Theses LUDs must encompass all resources needed to sustain aircraft war operations during a given period, including: personnel, support and test equipment, documentation, supply support, facilities, computer resources, and services. During peacetime, the AAF must acquire and maintain in a ready-to-use status all resources that are needed to constitute and sustain the different LUDs during a war contingency.

General Problem Statement

The AAF has not yet established a method for determining the capacity that a LUD must have to accomplish all the logistics functions needed to support aircraft activity in a given war scenario. Therefore, the need for establishing such a method has risen.

The current environment of the AAF is characterized by resource constraints that will affect logistics decision-makers twofold. First, scarce resources will have a high

incidence in the output of the planning process; limited human and physical means will lead to few options to materialize the logistics support. Second, a restricted amount of skilled human resources, limited computer systems and low compatibility of existing databases will bound the planning process itself.

The RAC 9 also defines the criteria that must be observed during the logistics planning process. Among them the following are relevant to this study:

(1) A logistics plan must support the operations plan (strategic or tactical) from which it derives;

(2) All necessary resources must be predicted;

(3) Unnecessary duplication of efforts must be avoided;

(4) To attain an efficient logistics system must be a prime goal for the logistics planner.

The problem that logistics decision makers are now facing can be conceptualized as follows: ***to develop a model able to determine the capacity that a Logistics Unit of Deployment must have in order to support wartime activity of an Air Unit.***

Research Objective

The aim of this research is: ***to develop a reduced-scale spreadsheet model able to compute the capacity of the aircraft maintenance function and its related supply support that a Logistics Unit of Deployment must have in order to support wartime activity of an Air Unit.***

Research Scope

Model Objective. To compute resources needed to support a given amount of wartime activity for a particular air unit.

Model Functional Areas. Two functional areas are explicitly cited in the research objective: maintenance and related supply. For the purpose of this work, maintenance is understood as "...all actions necessary for retaining a system or product in, or restoring it to, a desired operational state" (Blanchard 1997,15). Corrective, preventive maintenance activities are included.

In order to carry out these scheduled and unscheduled maintenance actions, consumable material, spare and repair parts are necessary. The model will address the supply of this kind of material and corresponding inventories.

Method of Model Implementation. Although the operation research methodology is not defined in the objective of this study, spreadsheet is the computer technique selected for model implementation. Therefore, the operations research methodology become constrained by the necessity of modeling the phenomenon with reasonable accuracy and by the need of implementing it on a spreadsheet platform.

Spreadsheet program was selected because it is a tool already available in the Argentine Air Force planning environment. This fact is expected to facilitate the understandability of the model and to reduce the learning curve effect during its implementation.

Scope of the Model. A reduced-scale model is going to be developed. The main effort will be devoted to isolate the different drivers of consumption of resources within the maintenance function and to find valid ways to model the relationship among such drivers and the amount of resources needed. At this stage the model is not intended to manage al the complexities of a full scale deployment of a weapon system; instead, the idea is to identify valid ways to model the core problem, and to use the model to demonstrate the feasibility of their implementation.

ATTACHMENT 2

Part I: Desirable Model Characteristics

Objective

The objective of this part of the survey is to rank the expectable characteristics of the model according to its relative importance within the particular environment of the Argentine Air Force.

Desirable Model Characteristics Definition

An effective model should be (Silver et al, 1998: 51 and Little, 1970: B-469-B471):

(1) **Understandable**: decision-makers must understand what is the mechanism of computation that the model uses and the underlying assumptions.

(2) **Complete**: all the relevant aspects to attain the objective of the model must be taken into account.

(3) **Evolutionary:** the model must admit modifications in order to capture new aspects of the changing environment.

(4) **Easy to control**: the operation of the model should not require that the user develop any special skill to make the model behave in the way he needs.

(5) **Easy to communicate with**: the interface between the user and the model should be facilitated by the layout of the model, inputs should be easy to change and output quickly to obtain. The communication should be carry out in the user language.

(6) **Robust:** the model should be insensitive to errors of input data.

(7) Adaptive: the model must be able to be used in different user's environments characterized by different availability of data. The model should be able to operate whit partial data.

Task

(1) Please, keeping in mind the intended objective and scope of this reduced scale spreadsheet model (see Attachment 1), write down on Table I these seven characteristics, in decreasing order of importance.

(2) If you would like to add any other characteristic that you deem important, please do so in the space named Comments I. It is desirable that you clarify the concept with a definition and rank it (Example: if you think that the new characteristic should be ranked between item third and fourth on table I indicate so by writing RANK=3.a)

ATTACHMENT 3

Part II: Aircraft Maintenance Resources to Be Computed

Objective

A variety of resources are needed to perform the aircraft maintenance function, and, as a consequence, may be objects of computation by the model that is under development. In order to maintain the initial complexity of the model low enough to allow its development as an individual thesis effort while attaining a significant contribution to the solution of managerial problem, the computation of some of these resources have to be postponed.

The objective of this part of the survey is to rank the resources according to their relative impact in the logistics planing process.

Resource Definition

Definitions for those resources are now provided (Blanchard et al, 1995:12-13).

(1) **Manpower:** personnel necessary for sustained maintenance of the aircraft throughout the deployment period. Personnel may be defined in terms of quantity, skills, and skill levels or using a combination of the preceding factors.

(2) **Technical manuals**: they include checkout procedures, inspection and calibration procedures, overhaul procedures, modification instructions, facility information, drawings, and specifications necessary to perform the maintenance function.

Thesetechnical manuals must cover not only the aircraft but also the test and support equipment, handling equipment, and facilities.

(3) **Computer resources**: this includes all computer equipment and accessories, software, program disks, databases, etc, needed to perform the maintenance function.

(4) **Supply support**: this category includes all the material needed to maintain the aircraft and sustain their operation.

a. **Consumable**: material that lost its identity due to its use (it wears out or disappears) or it is classified in this group due to its low cost.

b. **Reparable:** material whose operational condition may be recovered through a reparation process.

c. **TRAP**: it includes tanks, racks, adapters, and pylons needed to configure the aircraft.

d. **POL:** Fuel and lubricants.

NOTE: a, b and d are applicable not only to aircraft but also to test equipment, support equipment, handling equipment and facilities.

(5) **Test Equipment**: this category includes special condition-monitoring equipment, diagnostic and checkout equipment, metrology, and calibration equipment required to support scheduled and unscheduled maintenance actions associated with the aircraft and its weapons.

(6) **Support equipment**: It includes air ground equipment (AGE) (example: air compressor, bomb lift, hydraulic power cart, tow vehicle, etc), and handling equipment, needed to perform maintenance actions or support the operation of the aircraft.

(7) **Facilities**: this included fixed or mobile installations required for the accomplishment of scheduled or unscheduled maintenance actions on the aircraft and test and support equipment.

(8) **Packaging, handling and storage**: this category includes all the special materials, containers (reusable or disposable), and supplies needed to support the packaging, preservation, storage, and handling of aircraft oriented equipment, test and support equipment, spares and repair parts, technical manuals and mobile facilities.

Task

(1) Please, keeping in mind the intended objective of this reduced scale spreadsheet model (see Attachment 1), write down on Table II these twelve maintenance resources, in decreasing order of importance.

Note 1: High importance assigned to a resource means that the computation of this resource must be immediately attempted; whereas, low importance resource means that its computation may be delayed to a posterior evolution of the model.

Note 2:Supply Support resources must be ranked individually.

(2) If you would like to add any other resource that you deem important, please do so in the space named Comments II. It is desirable that you clarify the concept with a definition and rank it (Example: if you think that the new resource should be ranked between item third and fourth on table II indicate so by writing RANK=3.a)

ATTACHMENT 4

Part III: Model Conceptual Variables

Objective

From the review of literature concerning models that have been developed with similar purposes within the environment of the DoD, a number of conceptual variables have been found. These variables may operate as drivers of maintenance actions or as moderators of the amount or logistics resources used to perform these maintenance actions. Again, to control the initial complexity not all these variables can be included.

The objective of this part is to differentiate the impact of these conceptual variables in the use of logistics resources, in the particular environment of the Argentine Air Force.

Conceptual Variables Definitions

To facilitate the attainment of the objective of this part the following 30 conceptual variables were categorized in seven groups: aircraft design, operational policy, maintenance policy, supply policy, secondary logistics, environmental, and enemy action, as follows:

1. **Aircraft Design:** Within this group were classified the variables that are mainly determined by the particular way in which the aircraft has been conceived and produced.

a *Reliability parameters*: Includes all the values and functions needed to determine the probability that a particular piece of equipment successfully performs its intended function during a determined time interval.

b *Repair time distributions*: Values and functions needed to characterize the time required to performing a corrective or preventive ***maintenance action*** (1). It includes the time necessary to localize and isolate the fault, disassemble (gain access to the faulty unit), repair or replace the item, reassemble, adjust, align or calibrate, and verify the functioning condition.

c *Required resources*: This concept establishes the relationship among each maintenance action and the resources needed to perform it according to manufacturer instructions (see Attachment 3).

d *Alternative required resources*: A mix of resources different from the one established by the manufacturer that is able to perform the maintenance action at the same level of ***effectiveness*** (2) but with less ***efficiency*** (3).

e *Failure criticality*: measures the impact of a particular failure on the operational capability of the aircraft. The reparation of a highly critical failure can not be deferred.

2. **Operational Policy**: Within this group are included the variables that are under the control of the operational planners. They depict the magnitude of the air unit and its level of utilization deemed necessary to produce the intended military effect.

   a *Flying program*: this concept encompasses all the parameters needed to completely describe the planned air activity and its schedule. These parameters

may include operational variables such as: number of aircraft, aircraft type, mission type, required munitions, take-off time, sortie length, etc.

b *Alert schedule*: Includes all the parameters necessary to define the required speed of response of a group of aircraft that are going to be maintained ready for immediate use (alert status), in terms of type and number of aircraft, desired launch time, duration of the alert status, etc.

c *Mission priority*: defines the relative importance among the planned missions. It is intended to be used as a criterion to solve maintenance resource allocation conflicts.

d *Mission cancellation criterion*: it describes the tolerance that the mission admits to delay or lack of materiel. It can be expressed as a cancellation time, minimum number of aircraft available to perform the mission, minimum number of weapon available, etc.

e *Dispersion*: this concept refers to the physical location that each aircraft and maintenance resources have within the ***base.***[(5)]

f *Probability of retaining munitions/TRAP*: this concept depicts the likelihood that the munitions, tanks, racks, adapters, and pylons loaded to accomplish a particular mission can be reused.

3. **Maintenance Policy**: Within this group are included the variables that affect the maintenance function and are under the control of the logistics planners. They depict postures and criteria that shape the way in which the maintenance function is performed and resources are used.

a *Work shift policy*: criteria that must be satisfy while administering manpower, in terms of maximum time of continuous service, minimum number of workers due to safety reasons, time of shift change, overtime, etc.

b *Required skills level*: defines the personnel's knowledge and ability require to performing a particular maintenance action. It refers to different kind of skills and different levels within the same class.

c *Cross training*: depicts the possibility that the same person is able of performing tasks corresponding to different skill classifications, as a consequence of a formal training program received in those job areas.

d *Task organization*: describes the sequence in which specific tasks must be ordered following ***Standards Procedures*** [(4)]. It can include task network, task incompatibility, etc.

e *Task priority*: defines the criteria to be followed to assign resources to maintenance tasks that are waiting for them. Included in this criteria are the resource dispatch criterion, expedite repair, work-in-process preemption, shop repair priority, etc.

f *Tasks level:* defines the organizational level in which the maintenance action can be carried out. Essentially it must define the maximum level of maintenance action that are to be perform at ***base*** [(5)] level. It specifically have to establish whether the capability of repairing reparable parts is to be installed at base level or all the material is going to be send to other logistics units to be recovered.

g *Preventive inspection schedule*: defines the program of inceptions established by ***Standard Procedures***[4]***,*** and the feasibility of deferral of its accomplishment.

4. **Supply Policy**: Within this group are included the variables that affect the supply function and are under the control of the logistics planners. They depict postures and criteria that shape the way in which the supply function is performed and resources are distributed.

   a *Resource availability*: defines the quantity of resource already available or assigned by higher level of planning to support the activity of the air unit.

   b *Resupply procedure*: defines the sources and frequency (or interval) selected to attain the established inventory position. It includes depot and ***lateral resupply***[6].

   c *Cannibalization criterion*: establishes whether a grounded aircraft or a faulty ***LRU***[7] are going to be used as supply sources in order to consolidate backorders in the less possible number of units. It includes aircraft and LRU cannibalization criterion.

   d *Substitutability:* defines the possibility of using a part instead of other in order to perform the function of the latter with the same level of ***effectiveness***[2].

5. **Secondary Logistics**: within this group are classify variables related to the maintenance of ***physical resources***[8] needed to perform the aircraft maintenance function, which can affect the availability of such resources.

   a *Support equipment unscheduled maintenance*: defines the probability of failure and time required to recovering the operational capability of equipment needed to perform aircraft maintenance actions. It includes test equipment, air ground

equipment (AGE) (example: air compressor, bomb lift, hydraulic power cart, tow vehicle, etc)

b *Support equipment periodic servicing*: defines the preventive maintenance actions to be performed periodically in order to maintain the operational status of the equipment necessary to carry out aircraft maintenance actions.

c *Facility maintenance*: defines the corrective and preventive maintenance needed to maintain a predetermined operational condition of fixed installations needed to carry out aircraft maintenance actions.

6. **Environmental**: within this group are classifid variables related to weather conditions that may affect the amount of activity actually performed by the air unit, resources needed to support maintenance actions or the time to perform them.

a *Minimum weather condition*: defines the meteorological conditions that must be satisfied for a mission to be accomplished.

b *Weather dependent transit times*: defines the way in which meteorological conditions affect the mobility of maintenance resources when supporting aircraft maintenance activities.

7. **Enemy action**: within this group are classify variables related to hostile actions carried out by the enemy that may affect the amount of maintenance actions to be performed on the aircraft, support equipment and facilities (secondary logistic) or the availability of maintenance resources.

a *Battle damage*: defines the probability and extension of damage that aircraft may undergo during the accomplishment of war mission.

b *Combat losses*: defines the expected attrition of the number of aircraft that takes place during mission accomplishment.

c *Base attack damage*: depicts possibility of damage on own aircraft, and maintenance resources provoked by an enemy attack.

Task

Phase 1

Please, keeping in mind the intended objective of this reduced scale spreadsheet model, assign a score to each group of variables (column 3 of table III) using the following scale:

Score	Meaning
3	Variables of this group must be included in the initial model.
2	It is desirable that variables of this group be included in the initial model.
1	The effect of this group of variables may be incorporated in future evolutions of the model.

Phase 2

Please, assign a score to each variable (column 6 of table III) in order to reflect your opinion about the **relative importance** of that particular conceptual variable **within its group**. The scale to be applied is the following.

Score	Meaning
3	This particular variable must be included in the initial model.
2	It is desirable that this particular variable be included in the initial model.
1	The effect of this particular model may be incorporated in future developments of the model.

Phase 3

If you would like to add any other conceptual variable that you deemed important, please do so in the space named Comments III. It is desirable that you clarify the concept with a definition, classify it within a group of variables, and assigned a score.

ATTACHMENT 5

Definitions

(1) Maintenance action: Any task performed on the aircraft pursuing the objective of retaining or restoring it to, a desired operational state. It includes weapon loading and servicing (fueling, etc.)

(2) Effectiveness: degree of accomplishment of an objective.

(3) Efficiency: rate between the level of objective accomplishment and the resources used.

(4) Standard Procedures: particular way in which a task must be carry out, according to official doctrine or practices already accepted and that form part of the existent training.

(5) Base: this term refers to the location to which the air unit is deployed during wartime.

(6) Lateral resupply: the needed part is received from other base within the theater, which acts as an occasional source of supply.

(7) LRU: line replacement unit.

(8)Physical resources: this class excludes human resources.

ATTACHMENT 6

SURVEY FORM

Administrative Information

Name:			*Rank:*
Time of Service:	*Current Position:*		
Graduate Education:			
Carrier Information			
Years	Unit	Aircraft Type *	Main Logistics-Related Position
Deployment Experience			
How many exercises have you participated in:			
Have you deployed in wartime conditions?			

*F=Ground Attack Fighter T=Transport I=Interceptor H=Helicopter C=Close Air Support

Part I: Desirable Model Characteristics

Table I

Importance	Desired Model Characteristic
First	
Second	
Third	
Fourth	
Fifth	
Sixth	
Seventh	

Comments I

Part II: Aircraft Maintenance Resources To Be Computed

Table II

Importance	Resource
First	
Second	
Third	
Fourth	
Fifth	
Sixth	
Seventh	
Eighth	
Ninth	
Tenth	
Eleventh	
Twelve	

Comments II

Part III: Conceptual Variables

Table III

Group of Variables			Conceptual Variables		
Def. (1)	Name (2)	Score (3)	Def. (4)	Name (5)	Score (6)
1	**Aircraft Design**		1. a	Reliability parameters	
			1. b	Repair time distributions	
			1. c	Required resources	
			1. d	Alternative required resources	
			1. e	Failure criticality	
2	**Operational Policy**		2. a	Flying program	
			2. b	Alert schedule	
			2. c	Mission priority	
			2. d	Mission cancellation criterion	
			2. e	Dispersion	
			2. f	Probability of retaining munitions/TRAP	
3	**Maintenance Policy**		3. a	Work shift policy	
			3. b	Required skills level	
			3. c	Cross training	
			3. d	Task organization	
			3. e	Task priority	
			3. f	Tasks level	
			3. g	Preventive inspection schedule	
4	**Supply Policy**		4. a	Resource availability	
			4. b	Resupply procedure	
			4. c	Cannibalization criterion	
			4. d	Substitutability	
5	**Secondary Logistics**		5. a	Support equipment unscheduled maintenance	
			5. b	Support equipment periodic servicing	
			5. c	Facility maintenance	
6	**Environmental**		6. a	Minimum weather condition	
			6. b	Weather dependent transit times	
7	**Enemy Action**		7. a	Battle damage	
			7. b	Combat losses	
			7. c	Base attack damage	

(1) and (4) see Attachment 4

Comments III

APPENDIX E

Survey Analysis

Desirable Model Characteristics

Table E-1. Survey Results

Desirable Characteristic	Rico	Lombardi	Longo	Discoli	Santilli	Filgueira
(1)Understandable	4	7	7	1	5	1
(2) Complete	1	3	3	7	2	2
(3) Evolutionary	7	6	6	2	3	3
(4) Easy to control	6	1	1	4	6	6
(5) Easy to communicate with	3	4	2	5	1	4
(6) Robust	2	5	5	6	4	5
(7) Adaptive:	5	2	4	3	7	7

Table E-2. Preliminary Order of Characteristics According to the Mean of the Assigned Rank

	Sum of Ranks	Mean Rank	Mode
(2) Complete	18	3	3 and 2
(5) Easy to communicate with	19	3.166667	4
(4) Easy to control	24	4	6
(1)Understandable	25	4.166667	7and 1
(3) Evolutionary	27	4.5	6 and 3
(6) Robust	27	4.5	5
(7) Adaptive	28	4.666667	7

Analysis of the Statistical Significance of the Results

```
FRIEDMAN TWO WAY NONPARAMETRIC AOV

 FACTOR 1     MEAN   SAMPLE
VARIABLE      RANK    SIZE
---------    ------  ------
AD             4.67     6
CO             3.00     6
EC             4.00     6
EV             4.50     6
```

EW	3.17	6
RO	4.50	6
UN	4.17	6

FRIEDMAN STATISTIC	3.4286
P-VALUE, CHI-SQUARED APPROXIMATION	0.7534
DEGREES OF FREEDOM	6

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	3.29	7
2	3.64	7
3	3.57	7
4	3.64	7
5	3.21	7
6	3.64	7

FRIEDMAN STATISTIC, CORRECTED FOR TIES	0.4167
P-VALUE, CHI-SQUARED APPROXIMATION	0.9949
DEGREES OF FREEDOM	5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 42 MISSING CASES 0

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
AD	25.5	6
CO	15.5	6
EC	21.5	6
EV	24.5	6
EW	16.5	6
RO	24.5	6
UN	22.5	6
TOTAL	21.5	42

KRUSKAL-WALLIS STATISTIC	3.9048
P-VALUE, USING CHI-SQUARED APPROXIMATION	0.6896

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	6	576.000	96.0000	0.61	0.7175
WITHIN	35	5472.00	156.343		
TOTAL	41	6048.00			

TOTAL NUMBER OF VALUES THAT WERE TIED 42
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 42 MISSING CASES 0

WILCOXON SIGNED RANK TEST FOR CO - AD

```
SUM OF NEGATIVE RANKS                                   -16.000
SUM OF POSITIVE RANKS                                    5.0000

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)     0.1562

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION          1.048
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION             0.2945

TOTAL NUMBER OF VALUES THAT WERE TIED          6
NUMBER OF ZERO DIFFERENCES DROPPED             0
MAX. DIFF. ALLOWED BETWEEN TIES          0.00001

CASES INCLUDED 6    MISSING CASES 0
```

Conclusion

At a 95% confidence level, there is no evidence to reject the null hypothesis that states that all treatments (importance of conceptual variables) have the same mean.

APPENDIX F

Survey Analysis

Resources to Be Computed

Table F-1. Survey Results

Resources	Rico	Lombardi	Longo	Discoli	Santilli	Filgueira
(1) Manpower	1	1	1	4	1	1
(2) Technical manuals	2	8	9	9	6	8
(3) Computer resources	11	10	11	11	11	11
(4) Consumable	8	5	5	6	2	2
(5) Reparable	4	4	8	5	5	5
(6) TRAP	5	3	4	2	3	3
(7) POL	6	2	2	1	4	4
(8) Test Equipment	3	7	7	10	8	7
(9) Support equipment	7	6	3	3	7	6
(10) Facilities	9	9	6	7	10	9
(11) Packaging, handling and storage	10	11	10	8	9	10

Table F-2. Preliminary Order of Characteristics according to the Mean of the Assigned Rank

	Sum of Ranks	Mean Rank	Mode
(1) Manpower	9	1.5	1
(7) POL	19	3.166667	2 and 4
(6) TRAP	20	3.333333	3
(4) Consumable	28	4.666667	2 and 5
(5) Reparable	31	5.166667	5
(9) Support equipment	32	5.333333	3,6 and 7
(2) Technical manuals	42	7	8 and 9
(8) Test Equipment	42	7	7
(10) Facilities	50	8.333333	9
(11) Packaging, handling and storage	58	9.666667	10
(3) Computer resources	65	10.83333	11

Analysis of the Statistical Significance of the Results

FRIEDMAN TWO WAY NONPARAMETRIC AOV

FACTOR 1 VARIABLE	MEAN RANK	SAMPLE SIZE
CO	4.67	6
CR	10.83	6
FA	8.33	6
MA	1.50	6
PHS	9.67	6
POL	3.17	6
REP	5.17	6
SE	5.33	6
TE	7.00	6
TM	7.00	6
TRAP	3.33	6

FRIEDMAN STATISTIC	45.030
P-VALUE, CHI-SQUARED APPROXIMATION	0.0000
DEGREES OF FREEDOM	10

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	3.82	11
2	3.14	11
3	3.55	11
4	3.36	11
5	3.68	11
6	3.45	11

FRIEDMAN STATISTIC, CORRECTED FOR TIES	1.1111
P-VALUE, CHI-SQUARED APPROXIMATION	0.9531
DEGREES OF FREEDOM	5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 66 MISSING CASES 0

FRIEDMAN STATISTIC, CORRECTED FOR TIES	1.1111
P-VALUE, CHI-SQUARED APPROXIMATION	0.9531
DEGREES OF FREEDOM	5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 66 MISSING CASES 0

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
CO	25.5	6
CR	62.5	6
FA	47.5	6
MA	6.5	6
PHS	55.5	6
POL	16.5	6
REP	28.5	6
SE	29.5	6
TE	39.5	6
TM	39.5	6
TRAP	17.5	6
TOTAL	33.5	66

KRUSKAL-WALLIS STATISTIC 48.7828
P-VALUE, USING CHI-SQUARED APPROXIMATION 0.0000

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	10	17832.0	1783.20	16.54	0.0000
WITHIN	55	5928.00	107.782		
TOTAL	65	23760.0			

TOTAL NUMBER OF VALUES THAT WERE TIED 66
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 66 MISSING CASES 0

COMPARISONS OF MEAN RANKS

VARIABLE	MEAN RANK	HOMOGENEOUS GROUPS
CR	62.500	I
PHS	55.500	I I
FA	47.500	I I I
TE	39.500	I I I I
TM	39.500	I I I I
SE	29.500	I I I I
REP	28.500	I I I I
CO	25.500	.. I I I
TRAP	17.500	.... I I
POL	16.500	.... I I
MA	6.5000	 I

THERE ARE 4 GROUPS IN WHICH THE MEANS ARE NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

REJECTION LEVEL 0.050

CRITICAL Z VALUE	3.32
CRITICAL VALUE FOR COMPARISON	36.765

Pairwise Comparison at 95% Confidence Level

WILCOXON SIGNED RANK TEST FOR CO - MA

SUM OF NEGATIVE RANKS	0.0000
SUM OF POSITIVE RANKS	21.000
EXACT PROBABILITY OF A RESULT AS OR MORE EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)	0.0156
NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	2.097
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.0360

TOTAL NUMBER OF VALUES THAT WERE TIED	4
NUMBER OF ZERO DIFFERENCES DROPPED	0
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

WILCOXON SIGNED RANK TEST FOR CO - FA

SUM OF NEGATIVE RANKS	-21.000
SUM OF POSITIVE RANKS	0.0000
EXACT PROBABILITY OF A RESULT AS OR MORE EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)	0.0156
NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	2.097
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.0360

TOTAL NUMBER OF VALUES THAT WERE TIED	3
NUMBER OF ZERO DIFFERENCES DROPPED	0
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

CASES INCLUDED 6   MISSING CASES 0

WILCOXON SIGNED RANK TEST FOR FA - PHS

SUM OF NEGATIVE RANKS	-18.500
SUM OF POSITIVE RANKS	2.5000
EXACT PROBABILITY OF A RESULT AS OR MORE EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)	0.0469
NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	1.572
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.1159

TOTAL NUMBER OF VALUES THAT WERE TIED	4
NUMBER OF ZERO DIFFERENCES DROPPED	0
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

CASES INCLUDED 6   MISSING CASES 0

WILCOXON SIGNED RANK TEST FOR FA - CR

SUM OF NEGATIVE RANKS	-21.000
SUM OF POSITIVE RANKS	0.0000

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE) 0.0156

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	2.097
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.0360

TOTAL NUMBER OF VALUES THAT WERE TIED	4
NUMBER OF ZERO DIFFERENCES DROPPED	0
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

CASES INCLUDED 6   MISSING CASES 0

WILCOXON SIGNED RANK TEST FOR CR - PHS

SUM OF NEGATIVE RANKS	-2.5000
SUM OF POSITIVE RANKS	18.500

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE) 0.0469

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	1.572
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.1159

TOTAL NUMBER OF VALUES THAT WERE TIED	4
NUMBER OF ZERO DIFFERENCES DROPPED	0
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

CASES INCLUDED 6   MISSING CASES 0

Conclusions

(1) According to the results of the Friedman Two-Way Nonparametric AOV, we have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean; therefore, at least one treatment differs from the others.

(2) According to Kruskal-Wallis One-Way Nonparametric AOV and posterior comparison of means ranks, four homogeneous groups were identified with a

high area of overlapping. Nevertheless, at a 95% level of confidence, we can conclude that CR (computer resources) and MA (Manpower) have different means. Manpower has a lower rank than computer resources.

(3) Applying Wilcoxon Signed Rank Test we gather enough evidence to reject the null hypothesis (compared distributions have the same mean rank) when comparing FA (facilities) with CR (computer resources), CO (consumables) with FA (facilities), and MA (manpower) with Facilities)

(4) The data suggest (do not confirm due to the overlapping homogeneous groups) the existence of three groups with different levels of assigned importance. These groups are listed in decreasing order of importance:

- MA (manpower) - POL - TRAP
- CO (consumables) - REP (reparable) - SE (support equipment) - TM (technical manuals) - TE (test equipment)
- FA (facilities) - PHS (packaging, handling and storage) – CR (computer resources)

APPENDIX G

Survey Analysis
Conceptual Variables

Table G-1. Survey Results

V. Group	Conceptual Variable	Assigned Importance Score *					
		Rico	Lombardi	Longo	Discoli	Santilli	Filgueira
AD	Reliability parameters	4	9	6	9	9	9
AD	Repair time distributions	4	6	9	9	6	6
AD	Required resources	6	9	6	9	9	9
AD	Alternative required resources	6	3	1	3	3	3
AD	Failure criticality	6	6	9	3	9	9
OP	Flying program	9	9	9	9	9	9
OP	Alert schedule	9	9	9	9	9	9
OP	Mission priority	6	6	6	3	6	6
OP	Mission cancellation criterion	6	6	3	3	6	6
OP	Dispersion	9	9	9	9	6	6
OP	Probability of retaining munitions/TRAP	6	9	6	3	3	3
MP	Work shift policy	9	9	9	6	9	9
MP	Required skills level	6	9	6	2	9	9
MP	Cross training	6	3	3	2	6	3
MP	Task organization	6	6	6	6	6	2
MP	Task priority	3	6	9	4	9	9
MP	Tasks level	9	9	9	6	9	3
MP	Preventive inspection schedule	9	6	6	6	6	6
SP	Resource availability	9	9	6	6	9	9
SP	Resupply procedure	6	9	4	6	9	9
SP	Cannibalization criterion	9	9	6	2	9	9
SP	Substitutability	6	9	2	2	9	9
SL	Support equipment unscheduled maintenance	4	6	1	1	4	4
SL	Support equipment periodic servicing	6	6	1	3	6	6
SL	Facility maintenance	2	4	1	1	4	4
E	Minimum weather condition	2	2	1	1	2	4
E	Weather dependent transit times	4	4	1	1	4	2
EA	Battle damage	9	9	9	9	9	9
EA	Combat losses	6	9	9	9	9	9
EA	Base attack damage	6	9	9	9	9	9

Note: Assigned Importance Score = (Variable Group Score) * (Conceptual Variable Score)

Table G-2. Conceptual Variable Groups

ID	CONCEPTUAL VARIABLES	Observed			Surveyed		
		Freq	Rel. Freq.	Rescaled	Av.Score	Rel. Av. Scor	Rescaled
MP	Maintenance Policy	22	0.28571	28.571	6.43	0.15477	15.4772
AD	Aircraft Design	18	0.23377	23.377	6.5	0.15646	15.6457
OP	Operational Policy	16	0.20779	20.779	6.91	0.16633	16.6326
SP	Supply Policy	11	0.14286	14.286	7.165	0.17246	17.2464
EA	Enemy Action	5	0.06494	6.4935	8.66	0.20845	20.8449
SL	Secondary Logistics	3	0.03896	3.8961	3.55	0.08545	8.54495
E	Environmental	2	0.02597	2.5974	2.33	0.05608	5.60838
	SUM	77	1	100	41.545	1	100

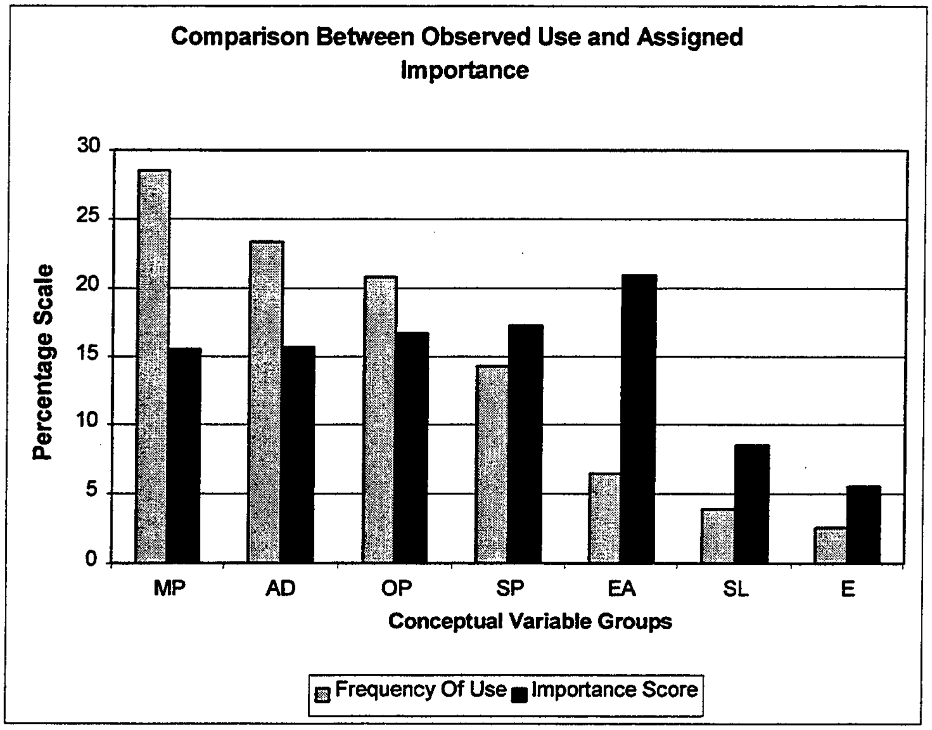


Figure G-1. Conceptual Variable Groups Comparison (Observed Use versus Assigned Importance)

Analysis of Survey Results

In this case de different number of variables that form each group precluded the use of Friedman Two Way Nonparametric AOV.

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV FOR SCORE BY VG

VG	MEAN RANK	SAMPLE SIZE
AD	15.9	5
E	1.8	2
EA	27.0	3
MP	15.1	7
OP	18.2	6
SL	4.8	3
SP	18.0	4
TOTAL	15.5	30

KRUSKAL-WALLIS STATISTIC 15.3540
P-VALUE, USING CHI-SQUARED APPROXIMATION 0.0177

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	6	1185.96	197.660	4.31	0.0047
WITHIN	23	1054.04	45.8278		
TOTAL	29	2240.00			

TOTAL NUMBER OF VALUES THAT WERE TIED 15
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 30 MISSING CASES 0

COMPARISONS OF MEAN RANKS OF SCORE BY VG

VG	MEAN RANK	HOMOGENEOUS GROUPS
EA	27.000	I
OP	18.167	I I
SP	18.000	I I
AD	15.900	I I
MP	15.071	I I
SL	4.8333	.. I
E	1.7500	.. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

REJECTION LEVEL 0.200
CRITICAL Z VALUE 2.59
CRITICAL VALUES OF DIFFERENCES VARY BETWEEN

COMPARISONS BECAUSE OF UNEQUAL SAMPLE SIZES.

Analysis of Survey Results Leaving out Enemy Attack Category

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV FOR SCORE BY VG

VG	MEAN RANK	SAMPLE SIZE
AD	15.9	5
E	1.8	2
MP	14.9	7
OP	17.3	6
SL	4.8	3
SP	18.0	4
TOTAL	14.0	27

KRUSKAL-WALLIS STATISTIC 11.2491
P-VALUE, USING CHI-SQUARED APPROXIMATION 0.0467

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	5	706.961	141.392	3.20	0.0265
WITHIN	21	927.039	44.1447		
TOTAL	26	1634.00			

TOTAL NUMBER OF VALUES THAT WERE TIED 11
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 27 MISSING CASES 0

COMPARISONS OF MEAN RANKS OF SCORE BY VG

VG	MEAN RANK	HOMOGENEOUS GROUPS
SP	18.000	I
OP	17.333	I
AD	15.900	I
MP	14.929	I
SL	4.8333	I
E	1.7500	I

THERE ARE NO SIGNIFICANT PAIRWISE DIFFERENCES AMONG THE MEANS.

REJECTION LEVEL 0.200
CRITICAL Z VALUE 2.47
CRITICAL VALUES OF DIFFERENCES VARY BETWEEN

COMPARISONS BECAUSE OF UNEQUAL SAMPLE SIZES.

Conclusions

(1) According to Kruskal-Wallis One-Way Nonparametric AOV, we have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean; therefore, at least one treatment differs from the others.

(2) Comparison of means ranks, four homogeneous groups were identified with a high area of overlapping. Nevertheless, at a 95% level of confidence, we can conclude that EA (enemy attack) and E (environmental) have different means. Enemy attack has a lower rank (more importance) than environmental variables.

(3) Leaving out EA (enemy attack) and according to Kruskal-Wallis One-Way Nonparametric AOV, we have no enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean.

(4) The data suggest (do not confirm due to the overlapping homogeneous groups) the existence of three groups with different levels of assigned importance. These groups are listed in decreasing order of importance:

- EA (enemy attack)
- MP (maintenance policy) - AD (aircraft design) - OP (operational policy) - SP (supply policy)
- SL (secondary Logistics) - E (environmental)

Table G-3. Aircraft Design Variables

ID	CONCEPTUAL VARIABLES	Observed			Surveyed		
		Freq	Rel. Freq.	Rescaled	Score	Rel. Score.	Rescaled
RP	Reliability parameters	6	0.33333	33.333	7.667	0.2359	23.5897
RTD	Repair time distributions	6	0.33333	33.333	6.667	0.20513	20.5128
RR	Required resources	3	0.16667	16.667	8	0.24615	24.6154
FC	Failure criticality	2	0.11111	11.111	7	0.21538	21.5385
ARR	Alternative required resources	1	0.05556	5.5556	3.167	0.09744	9.74359
	SUM	18	1	100	32.5	1	100

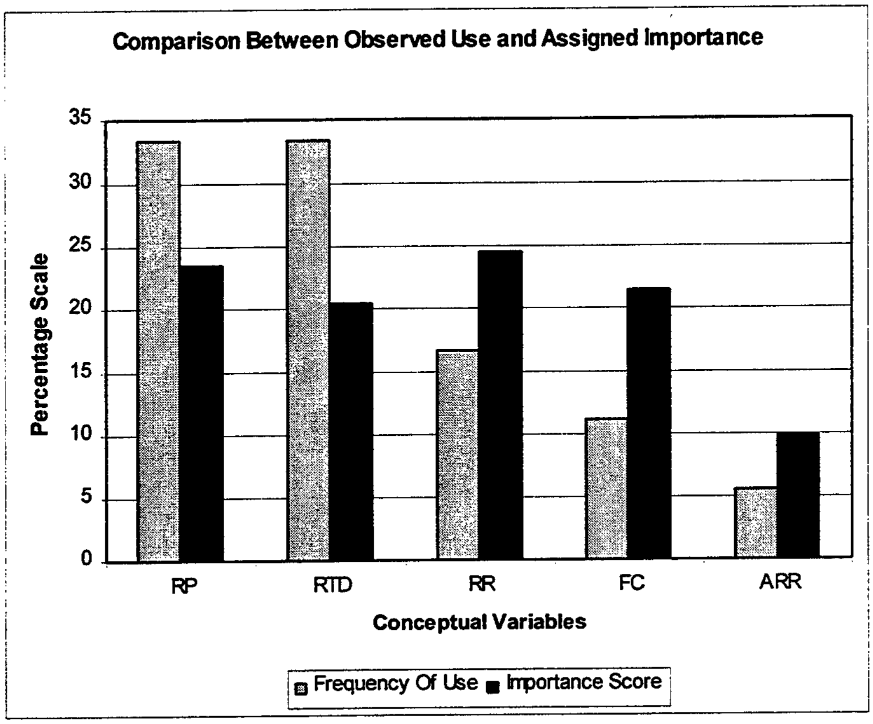


Figure G-2. Aircraft Design Conceptual Variables Comparison (Observed Use Versus Assigned Importance)

Statistical Analysis of Survey Results

```
FRIEDMAN TWO WAY NONPARAMETRIC AOV

 FACTOR 1     MEAN   SAMPLE
VARIABLE      RANK    SIZE
---------    ------  ------
RP             3.42     6
RTD            2.75     6
```

RR	3.83	6
FC	3.42	6
ARR	1.58	6

FRIEDMAN STATISTIC, CORRECTED FOR TIES	9.1429
P-VALUE, CHI-SQUARED APPROXIMATION	0.0576
DEGREES OF FREEDOM	4

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	2.40	5
2	3.60	5
3	3.00	5
4	3.80	5
5	4.10	5
6	4.10	5

FRIEDMAN STATISTIC, CORRECTED FOR TIES	4.2537
P-VALUE, CHI-SQUARED APPROXIMATION	0.5135
DEGREES OF FREEDOM	5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 30 MISSING CASES 0

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
ARR	5.0	6
FC	17.0	6
RP	19.4	6
RR	20.3	6
RTD	15.8	6
TOTAL	15.5	30

KRUSKAL-WALLIS STATISTIC	13.1929
P-VALUE, USING CHI-SQUARED APPROXIMATION	0.0104

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	4	907.583	226.896	5.22	0.0034
WITHIN	25	1087.42	43.4967		
TOTAL	29	1995.00			

TOTAL NUMBER OF VALUES THAT WERE TIED 29
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

```
CASES INCLUDED 30    MISSING CASES 0
```

COMPARISONS OF MEAN RANKS

VARIABLE	MEAN RANK	HOMOGENEOUS GROUPS
RR	20.333	I
RP	19.417	I
FC	17.000	I I
RTD	15.750	I I
ARR	5.0000	.. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

REJECTION LEVEL	0.050
CRITICAL Z VALUE	2.81
CRITICAL VALUE FOR COMPARISON	14.267

Conclusions

(1) According to the results of the Friedman Two-Way Nonparametric AOV, we do not have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean. (observed p-value = 0.0576 is slightly greater than the analysis limit alpha = 0.05)

(2) According to Kruskal-Wallis One-Way Nonparametric AOV, this test suggest the existence of enough evidence to reject the null hypothesis; therefore, at least the mean rank of one group is different from the others.

(3) The comparison of mean of the groups (Kruskal-Wallis) suggest (do not confirm duet to the relaxation of assumption of independence necessary to perform this test) that two groups with different assigned importance. Those groups are listed in descending order of importance:

- RR (resources Required) - RP (Reliability Parameters)

- FC (Failure criticality) - RTD (Repair Time Distributions) - ARR (Alternative Required Resources)

(4) RP and RR are within the three variables that the considered models uses the most.

Table G-4: Operational Policy Conceptual Variables

ID	CONCEPTUAL VARIABLES	Observed			Surveyed		
		Freq	Rel. Freq.	Rescaled	Score	Rel. Score.	Rescaled
FP	Flying program	6	0.375	37.5	9	0.21687	21.6867
MCC	Mission cancellation criterion	3	0.1875	18.75	5	0.12048	12.0482
D	Dispersion	3	0.1875	18.75	8	0.19277	19.2771
AS	Alert schedule	2	0.125	12.5	9	0.21687	21.6867
MP	Mission priority	1	0.0625	6.25	5.5	0.13253	13.253
PRM	Probability of retaining munitions/TRAP	1	0.0625	6.25	5	0.12048	12.0482
	SUM	16	1	100	41.5	1	100

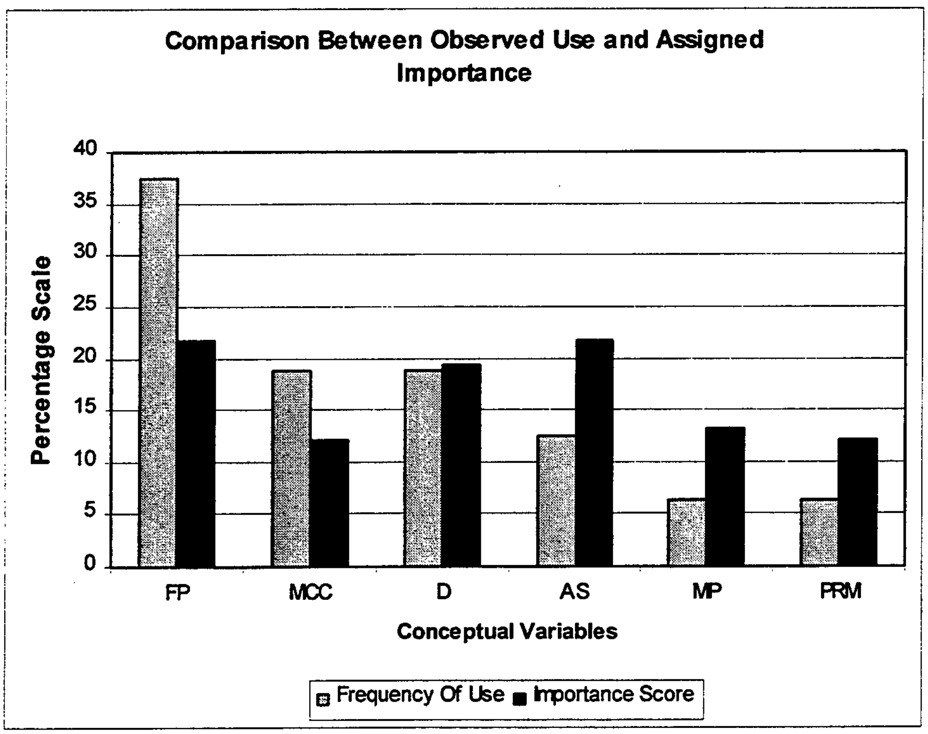


Figure G-3. Operational Policy Conceptual Variables Comparison (Observed Use Versus Assigned Importance)

FRIEDMAN TWO WAY NONPARAMETRIC AOV

```
 FACTOR 1     MEAN    SAMPLE
VARIABLE      RANK     SIZE
```

FP	5.08	6
MCC	2.08	6
D	4.25	6
AS	5.08	6
MP	2.33	6
PRM	2.17	6

FRIEDMAN STATISTIC, CORRECTED FOR TIES 22.976
P-VALUE, CHI-SQUARED APPROXIMATION 0.0003
DEGREES OF FREEDOM 5

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	4.08	6
2	4.33	6
3	3.58	6
4	2.67	6
5	3.17	6
6	3.17	6

FRIEDMAN STATISTIC, CORRECTED FOR TIES 7.5806
P-VALUE, CHI-SQUARED APPROXIMATION 0.1809
DEGREES OF FREEDOM 5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
FP	28.0	6
AS	28.0	6
D	23.0	6
MP	11.4	6
MCC	9.8	6
PRM	10.8	6
TOTAL	18.5	36

KRUSKAL-WALLIS STATISTIC 24.7385
P-VALUE, USING CHI-SQUARED APPROXIMATION 0.0002

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	5	2316.58	463.317	14.46	0.0000
WITHIN	30	960.917	32.0306		
TOTAL	35	3277.50			

TOTAL NUMBER OF VALUES THAT WERE TIED 36
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 36   MISSING CASES 0

COMPARISONS OF MEAN RANKS

VARIABLE	MEAN RANK	HOMOGENEOUS GROUPS
FP	28.000	I
AS	28.000	I
D	23.000	I I
MP	11.417	I I
PRM	10.750	I I
MCC	9.8333	.. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

REJECTION LEVEL	0.050
CRITICAL Z VALUE	2.94
CRITICAL VALUE FOR COMPARISON	17.854

WILCOXON SIGNED RANK TEST FOR D - MP

SUM OF NEGATIVE RANKS	0.0000
SUM OF POSITIVE RANKS	10.000
EXACT PROBABILITY OF A RESULT AS OR MORE EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)	0.0625
NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	1.643
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.1003

TOTAL NUMBER OF VALUES THAT WERE TIED	3
NUMBER OF ZERO DIFFERENCES DROPPED	2
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

CASES INCLUDED 4   MISSING CASES 2

WILCOXON SIGNED RANK TEST FOR D - PRM

SUM OF NEGATIVE RANKS	0.0000
SUM OF POSITIVE RANKS	15.000
EXACT PROBABILITY OF A RESULT AS OR MORE EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)	0.0312
NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	1.888
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.0591

TOTAL NUMBER OF VALUES THAT WERE TIED	4
NUMBER OF ZERO DIFFERENCES DROPPED	1
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

```
CASES INCLUDED 5    MISSING CASES 1
```

WILCOXON SIGNED RANK TEST FOR D - MCC

```
SUM OF NEGATIVE RANKS                                     0.0000
SUM OF POSITIVE RANKS                                     10.000

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)       0.0625

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION           1.643
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION              0.1003

TOTAL NUMBER OF VALUES THAT WERE TIED        4
NUMBER OF ZERO DIFFERENCES DROPPED           2
MAX. DIFF. ALLOWED BETWEEN TIES        0.00001

CASES INCLUDED 4    MISSING CASES 2
```

Conclusions

(1) According to the results of the Friedman Two-Way Nonparametric AOV, we do not have enough evidence to reject the null hypothesis that state that all treatments (importance of conceptual variables) have the same mean.

(2) According to Kruskal-Wallis One-Way Nonparametric AOV, we do not have enough evidence to reject the null hypothesis that state that all treatments (importance of conceptual variables) have the same mean.

(3) Applying Wilcoxon Signed Rank Test we gather enough evidence to reject the null hypothesis (compared distributions have the same mean rank) when comparing the group form by FP (flying program) and AS (alert status) and MCC (mission cancellation criterion). More over when D (dispersion) was compared with: MP (mission priority); PRM (probability of retaining

munitions/TRAP and MCC (mission cancellation criterion) the mull hypothesis was rejected at a minimum confidence level of 90%).

(4) The data suggest (do not confirm due to the overlapping homogeneous groups) the existence of two groups with different levels of assigned importance. These groups are listed in decreasing order of importance:

- FP (flying program) - AS (alert status) - D (dispersion)
- MP (mission priority) - PRM (probability of retaining munitions/TRAP - MCC (mission cancellation criterion)

(5) FP (flying program) and AS (alert status) are within the three variables that the considered models uses the most.

Table G-5. Maintenance Policy Conceptual Variables

		Observed			Surveyed		
ID	CONCEPTUAL VARIABLES	Freq	Rel. Freq.	Rescaled	Score	Rel. Score.	Rescaled
TL	Tasks level	6	0.27273	27.273	7.5	0.16605	16.6052
WSP	Work shift policy	4	0.18182	18.182	8.5	0.18819	18.8192
TP	Task priority	4	0.18182	18.182	6.667	0.1476	14.7601
RSL	Required skills level	3	0.13636	13.636	6.833	0.15129	15.1292
CT	Cross training	2	0.09091	9.0909	3.833	0.08487	8.48708
TO	Task organization	2	0.09091	9.0909	5.333	0.11808	11.8081
PIS	Preventive inspection schedule	1	0.04545	4.5455	6.5	0.14391	14.3911
	SUM	22	1	100	45.17	1	100

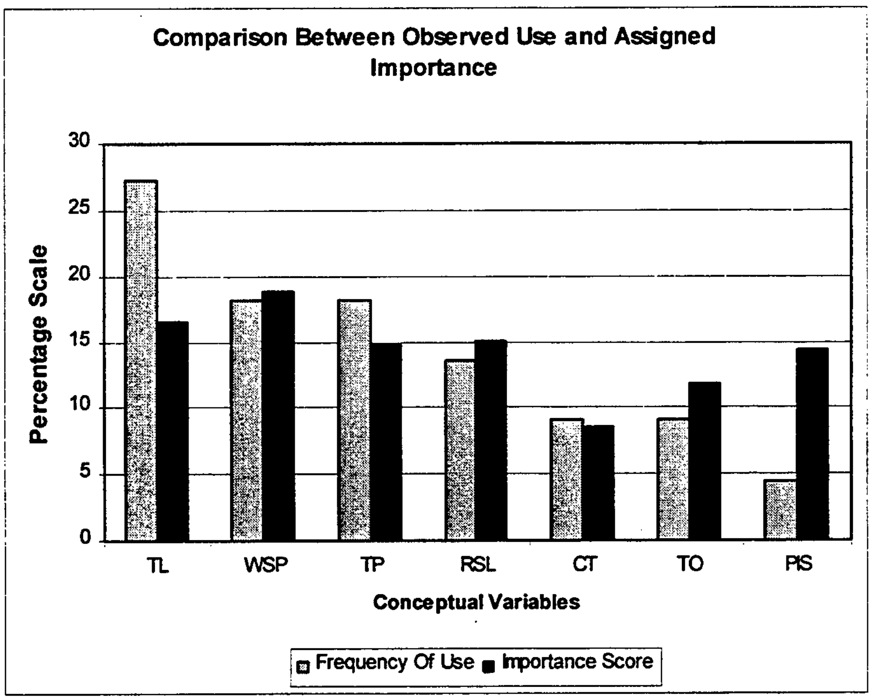


Figure G-4. Maintenance Policy Conceptual Variables Comparison (Observed Use Versus Assigned Importance)

```
FRIEDMAN TWO WAY NONPARAMETRIC AOV

 FACTOR 1     MEAN   SAMPLE
VARIABLE      RANK    SIZE
---------    ------  ------
```

TL	5.25	6
WSP	5.83	6
TP	4.08	6
RSL	4.17	6
CT	1.83	6
TO	2.92	6
PIS	3.92	6

FRIEDMAN STATISTIC, CORRECTED FOR TIES 16.596
P-VALUE, CHI-SQUARED APPROXIMATION 0.0109
DEGREES OF FREEDOM 6

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	3.93	7
2	3.79	7
3	3.71	7
4	2.00	7
5	4.43	7
6	3.14	7

FRIEDMAN STATISTIC, CORRECTED FOR TIES 10.807
P-VALUE, CHI-SQUARED APPROXIMATION 0.0553
DEGREES OF FREEDOM 5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 42 MISSING CASES 0

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
WSP	31.8	6
TL	27.0	6
RSL	23.6	6
TP	22.8	6
PIS	20.8	6
TO	15.3	6
CT	9.3	6
TOTAL	21.5	42

KRUSKAL-WALLIS STATISTIC 14.9056
P-VALUE, USING CHI-SQUARED APPROXIMATION 0.0210

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	6	1967.00	327.833	3.33	0.0106

WITHIN	35	3443.50	98.3857
TOTAL	41	5410.50	

TOTAL NUMBER OF VALUES THAT WERE TIED 41
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 42 MISSING CASES 0

COMPARISONS OF MEAN RANKS

VARIABLE	MEAN RANK	HOMOGENEOUS GROUPS
WSP	31.750	I
TL	27.000	I I
RSL	23.583	I I
TP	22.750	I I
PIS	20.750	I I
TO	15.333	I I
CT	9.3333	.. I

THERE ARE 2 GROUPS IN WHICH THE MEANS ARE
NOT SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

REJECTION LEVEL	0.050
CRITICAL Z VALUE	3.04
CRITICAL VALUE FOR COMPARISON	21.518

Conclusions

(1) According to the results of the Friedman Two-Way Nonparametric AOV, we have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean; therefore, at least one treatment differs from the others.

(2) According to Kruskal-Wallis One-Way Nonparametric AOV and posterior comparison of means ranks, two homogeneous groups were identified with a great area of overlapping. Nevertheless, at a 95% level of confidence, we can conclude that WSP (work shift policy) and CT (cross training) have different means. WSP has a higher rank than CT.

(3) The data suggest (do not confirm due to the overlapping homogeneous groups) the existence of three groups with different levels of assigned importance. These groups are listed in decreasing order of importance:

- WSP (work shift policy)
- TL (task level) - RSL (required skills level) - TP (task priority) - PIS (preventive inspection scheduled) - TO (task organization)
- CT (cross training)

Table G-6. Supply Policy Conceptual Variables

ID	CONCEPTUAL VARIABLES	Observed			Surveyed		
		Freq	Rel. Freq.	Rescaled	Score	Rel. Score.	Rescaled
RA	Resource availability	4	0.36364	36.364	8	0.27907	27.907
RP	Resupply procedure	3	0.27273	27.273	7.167	0.25	25
CC	Cannibalization criterion	2	0.18182	18.182	7.333	0.25581	25.5814
S	Substitutability	2	0.18182	18.182	6.167	0.21512	21.5116
	SUM	11	1	100	28.67	1	100

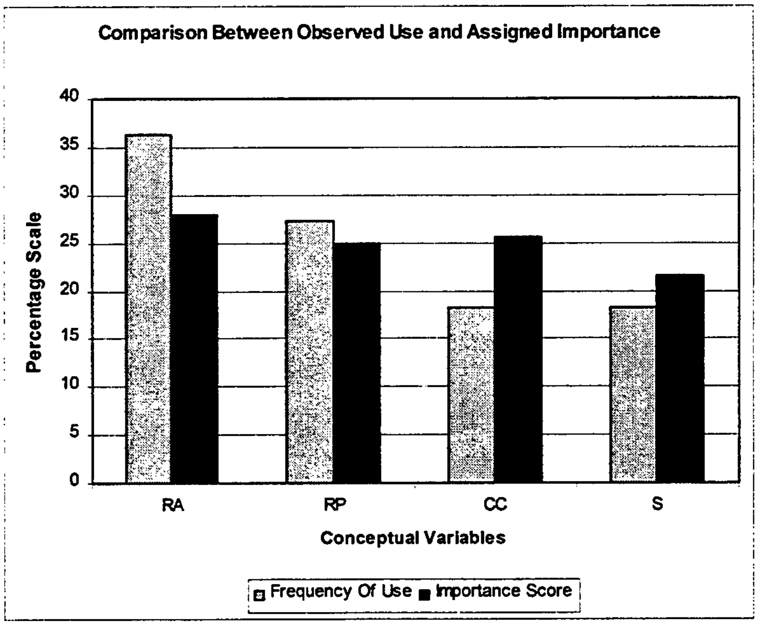


Figure G-5. Supply Policy Conceptual Variables Comparison (Observed Use Versus Assigned Importance)

```
FRIEDMAN TWO WAY NONPARAMETRIC AOV

 FACTOR 1      MEAN    SAMPLE
VARIABLE       RANK     SIZE
---------     ------   ------
RA              2.83      6
RP              2.58      6
CC              2.58      6
S               2.00      6

FRIEDMAN STATISTIC, CORRECTED FOR TIES     3.3750
P-VALUE, CHI-SQUARED APPROXIMATION         0.3373
DEGREES OF FREEDOM                              3
```

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	3.25	4
2	4.63	4
3	1.75	4
4	2.13	4
5	4.63	4
6	4.63	4

FRIEDMAN STATISTIC, CORRECTED FOR TIES 13.558
P-VALUE, CHI-SQUARED APPROXIMATION 0.0187
DEGREES OF FREEDOM 5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 24 MISSING CASES 0

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
RA	13.7	6
CC	12.8	6
RP	13.2	6
S	10.3	6
TOTAL	12.5	24

KRUSKAL-WALLIS STATISTIC 1.0633
P-VALUE, USING CHI-SQUARED APPROXIMATION 0.7859

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	3	39.6667	13.2222	0.32	0.8086
WITHIN	20	818.333	40.9167		
TOTAL	23	858.000			

TOTAL NUMBER OF VALUES THAT WERE TIED 23
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 24 MISSING CASES 0

COMPARISONS OF MEAN RANKS

VARIABLE	MEAN RANK	HOMOGENEOUS GROUPS
RA	13.667	I
RP	13.167	I
CC	12.833	I

```
S              10.333    I

THERE ARE NO SIGNIFICANT PAIRWISE DIFFERENCES AMONG THE MEANS.

REJECTION LEVEL                       0.050
CRITICAL Z VALUE                       2.64
CRITICAL VALUE FOR COMPARISON        10.771
```

WILCOXON SIGNED RANK TEST FOR RA - S

```
SUM OF NEGATIVE RANKS                                     0.0000
SUM OF POSITIVE RANKS                                     6.0000

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)        0.1250

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION            1.336
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION               0.1814

TOTAL NUMBER OF VALUES THAT WERE TIED        2
NUMBER OF ZERO DIFFERENCES DROPPED           3
MAX. DIFF. ALLOWED BETWEEN TIES        0.00001

CASES INCLUDED 3    MISSING CASES 3
```

Conclusions

(1) According to the results of the Friedman Two-Way Nonparametric AOV, we do not have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean.

(2) According to Kruskal-Wallis One-Way Nonparametric AOV, we do not have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean.

(3) Applying Wilcoxon Signed Rank Test we do not have enough evidence to reject the null hypothesis (compared distributions have the same mean rank) when comparing RA (resource availability) with S (substitutability)

(4) The data suggest that all conceptual variables have the same assigned importance.

Table G-7. Secondary Logistics Conceptual Group

		Observed			Surveyed		
ID	CONCEPTUAL VARIABLES	Freq	Rel. Freq.	Rescaled	Score	Rel. Score.	Rescaled
SEUM	Support equipment unscheduled maintenance	1	0.33333	33.333	3.333	0.3125	31.25
SEPS	Support equipment periodic servicing	1	0.33333	33.333	4.667	0.4375	43.75
FM	Facility maintenance	1	0.33333	33.333	2.667	0.25	25
	SUM	3	1	100	10.67	1	100

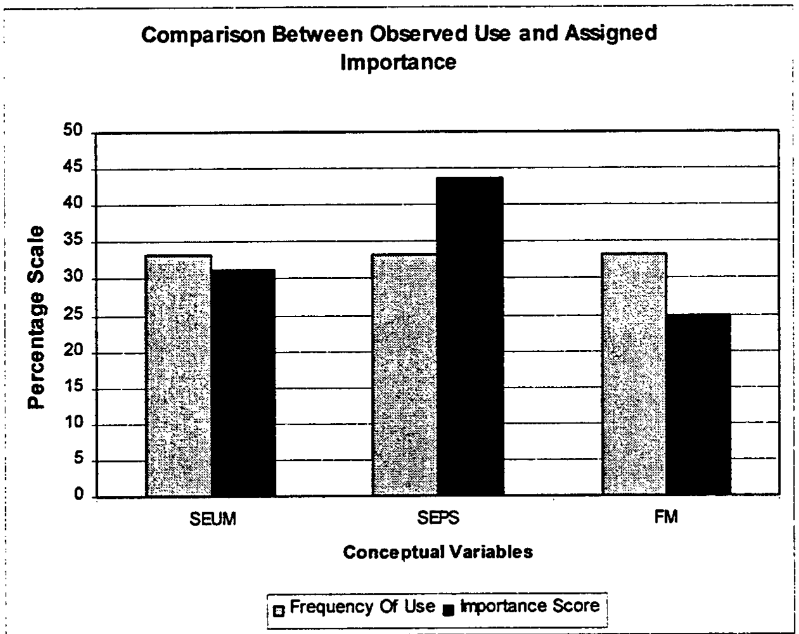


Figure G-6. Secondary logistics Conceptual Variables Comparison (Observed Use Versus Assigned Importance)

```
FRIEDMAN TWO WAY NONPARAMETRIC AOV

 FACTOR 1     MEAN   SAMPLE
VARIABLE      RANK    SIZE
---------    ------  ------
SEUM          1.83      6
SEPS          2.75      6
FM            1.42      6

FRIEDMAN STATISTIC, CORRECTED FOR TIES      8.3750
P-VALUE, CHI-SQUARED APPROXIMATION          0.0152
DEGREES OF FREEDOM                               2
```

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	3.83	3
2	5.17	3
3	1.33	3
4	1.67	3
5	4.50	3
6	4.50	3

FRIEDMAN STATISTIC, CORRECTED FOR TIES	13.706
P-VALUE, CHI-SQUARED APPROXIMATION	0.0176
DEGREES OF FREEDOM	5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 18 MISSING CASES 0

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
SEPS	12.3	6
SEUM	8.9	6
FM	7.3	6
TOTAL	9.5	18

KRUSKAL-WALLIS STATISTIC	3.0647
P-VALUE, USING CHI-SQUARED APPROXIMATION	0.2160

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	2	80.5833	40.2917	1.65	0.2252
WITHIN	15	366.417	24.4278		
TOTAL	17	447.000			

TOTAL NUMBER OF VALUES THAT WERE TIED 16
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 18 MISSING CASES 0

COMPARISONS OF MEAN RANKS

VARIABLE	MEAN RANK	HOMOGENEOUS GROUPS
SEPS	12.333	I
SEUM	8.9167	I
FM	7.2500	I

THERE ARE NO SIGNIFICANT PAIRWISE DIFFERENCES AMONG THE MEANS.

REJECTION LEVEL	0.050
CRITICAL Z VALUE	2.39
CRITICAL VALUE FOR COMPARISON	7.3787

WILCOXON SIGNED RANK TEST FOR SEPS - FM

SUM OF NEGATIVE RANKS	0.0000
SUM OF POSITIVE RANKS	15.000

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE) 0.0312

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	1.888
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.0591

TOTAL NUMBER OF VALUES THAT WERE TIED	4
NUMBER OF ZERO DIFFERENCES DROPPED	1
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

CASES INCLUDED 5 MISSING CASES 1

WILCOXON SIGNED RANK TEST FOR SEPS - SEUM

SUM OF NEGATIVE RANKS	0.0000
SUM OF POSITIVE RANKS	10.000

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE) 0.0625

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION	1.643
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION	0.1003

TOTAL NUMBER OF VALUES THAT WERE TIED	4
NUMBER OF ZERO DIFFERENCES DROPPED	2
MAX. DIFF. ALLOWED BETWEEN TIES	0.00001

CASES INCLUDED 4 MISSING CASES 2

Conclusions

(1) According to the results of the Friedman Two-Way Nonparametric AOV, we have enough evidence to reject the null hypothesis that state that all treatments (importance of conceptual) have the same mean; therefore, at least one treatment differs from the others.

(2) According to Kruskal-Wallis One-Way Nonparametric AOV, we do not have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean.

(3) Applying Wilcoxon Signed Rank Test we gather enough evidence to reject the null hypothesis (compared distributions have the same mean rank) when comparing SEPS (Support equipment periodic servicing) with FM (facility maintenance)

(4) The data suggest (do not confirm due to the overlapping homogeneous groups) the existence of two groups with different levels of assigned importance. These groups are listed in decreasing order of importance:

- SEPS (support equipment periodic servicing)
- FA (facility maintenance) - SEUM (support equipment unscheduled maintenance)

Table G-8. Environmental Conceptual Variables

		Observed			Surveyed		
ID	CONCEPTUAL VARIABLES	Freq	Rel. Freq.	Rescaled	Score	Rel. Score.	Rescaled
MWC	Minimum weather condition	1	0.5	50	2	0.42857	42.8571
WDTT	Weather dependent transit times	1	0.5	50	2.667	0.57143	57.1429
	SUM	2	1	100	4.667	1	100

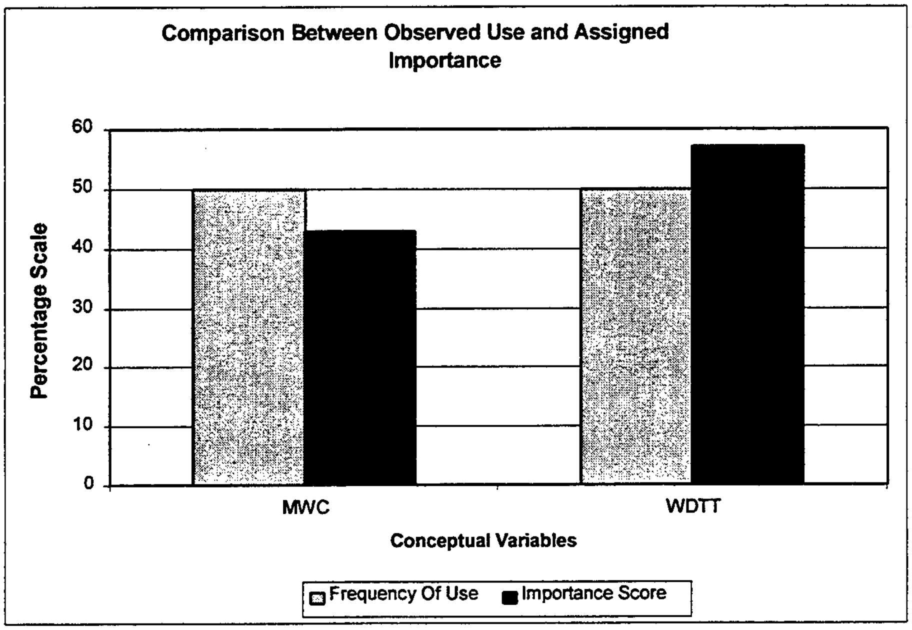


Figure G-7. Environmental Conceptual Variables Comparison (Observed Use Versus Assigned Importance)

WILCOXON SIGNED RANK TEST FOR MWC - WDTT

```
SUM OF NEGATIVE RANKS                                    -7.5000
SUM OF POSITIVE RANKS                                     2.5000

EXACT PROBABILITY OF A RESULT AS OR MORE
EXTREME THAN THE OBSERVED RANKS (1 TAILED P-VALUE)      0.1875

NORMAL APPROXIMATION WITH CONTINUITY CORRECTION           0.730
TWO TAILED P-VALUE FOR NORMAL APPROXIMATION              0.4652

TOTAL NUMBER OF VALUES THAT WERE TIED         4
NUMBER OF ZERO DIFFERENCES DROPPED            2
MAX. DIFF. ALLOWED BETWEEN TIES         0.00001

CASES INCLUDED 4    MISSING CASES 2
```

Conclusion

(1) Applying Wilcoxon Signed Rank Test we gather enough evidence to reject the null hypothesis (compared distributions have the same mean rank) when comparing the two variables.

(2) The data suggest that there is no difference between the mean of the assigned importance of these two variables.

Table G-9. Enemy Action Conceptual Variables

ID	CONCEPTUAL VARIABLES	Observed			Surveyed		
		Freq	Rel. Freq.	Rescaled	Score	Rel. Score.	Rescaled
BD	Battle damage	2	0.4	40	9	0.34615	34.6154
CL	Combat losses	2	0.4	40	8.5	0.32692	32.6923
BAD	Base attack damage	1	0.2	20	8.5	0.32692	32.6923
	SUM	5	1	100	26	1	100

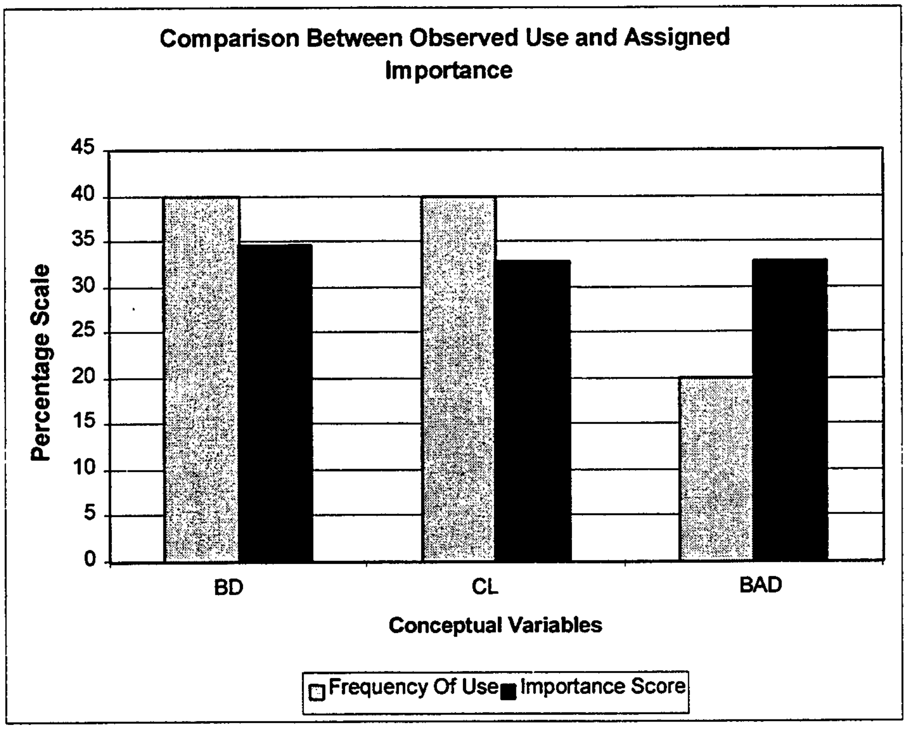


Figure G-8. Enemy Action Conceptual Variables Comparison (Observed Use Versus Assigned Importance)

```
FRIEDMAN TWO WAY NONPARAMETRIC AOV

 FACTOR 1     MEAN   SAMPLE
VARIABLE      RANK    SIZE
---------    ------  ------
BD             2.17     6
CL             1.92     6
BAD            1.92     6

FRIEDMAN STATISTIC, CORRECTED FOR TIES    2.0000
P-VALUE, CHI-SQUARED APPROXIMATION        0.3679
DEGREES OF FREEDOM                             2
```

FACTOR 2 CASES	MEAN RANK	SAMPLE SIZE
1	1.83	3
2	3.83	3
3	3.83	3
4	3.83	3
5	3.83	3
6	3.83	3

FRIEDMAN STATISTIC, CORRECTED FOR TIES	10.000
P-VALUE, CHI-SQUARED APPROXIMATION	0.0752
DEGREES OF FREEDOM	5

MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 18 MISSING CASES 0

KRUSKAL-WALLIS ONE-WAY NONPARAMETRIC AOV

VARIABLE	MEAN RANK	SAMPLE SIZE
BAD	9.0	6
BD	10.5	6
CL	9.0	6
TOTAL	9.5	18

KRUSKAL-WALLIS STATISTIC	1.0625
P-VALUE, USING CHI-SQUARED APPROXIMATION	0.5879

PARAMETRIC AOV APPLIED TO RANKS

SOURCE	DF	SS	MS	F	P
BETWEEN	2	9.00000	4.50000	0.50	0.6163
WITHIN	15	135.000	9.00000		
TOTAL	17	144.000			

TOTAL NUMBER OF VALUES THAT WERE TIED 18
MAX. DIFF. ALLOWED BETWEEN TIES 0.00001

CASES INCLUDED 18 MISSING CASES 0

COMPARISONS OF MEAN RANKS

VARIABLE	MEAN RANK	HOMOGENEOUS GROUPS
BD	10.500	I
BAD	9.0000	I

```
CL            9.0000    I

THERE ARE NO SIGNIFICANT PAIRWISE DIFFERENCES AMONG THE MEANS.

REJECTION LEVEL                    0.050
CRITICAL Z VALUE                    2.39
CRITICAL VALUE FOR COMPARISON     7.3787
```

Conclusion

(1) According to the results of the Friedman Two-Way Nonparametric AOV, we have enough evidence to reject the null hypothesis that state that all treatments (importance of conceptual) have the same mean; therefore, at least one treatment differs from the others.

(2) According to Kruskal-Wallis One-Way Nonparametric AOV, we do not have enough evidence to reject the null hypothesis that state that all treatments (importance of resources) have the same mean.

(3) Wilcoxon Signed Rank Test for BD (battle damage) and CL (combat looses) cannot be applied due to few untied pairs.

(4) The data suggest that there is no difference between the mean of the assigned importance of these two variables.

APPENDIX H

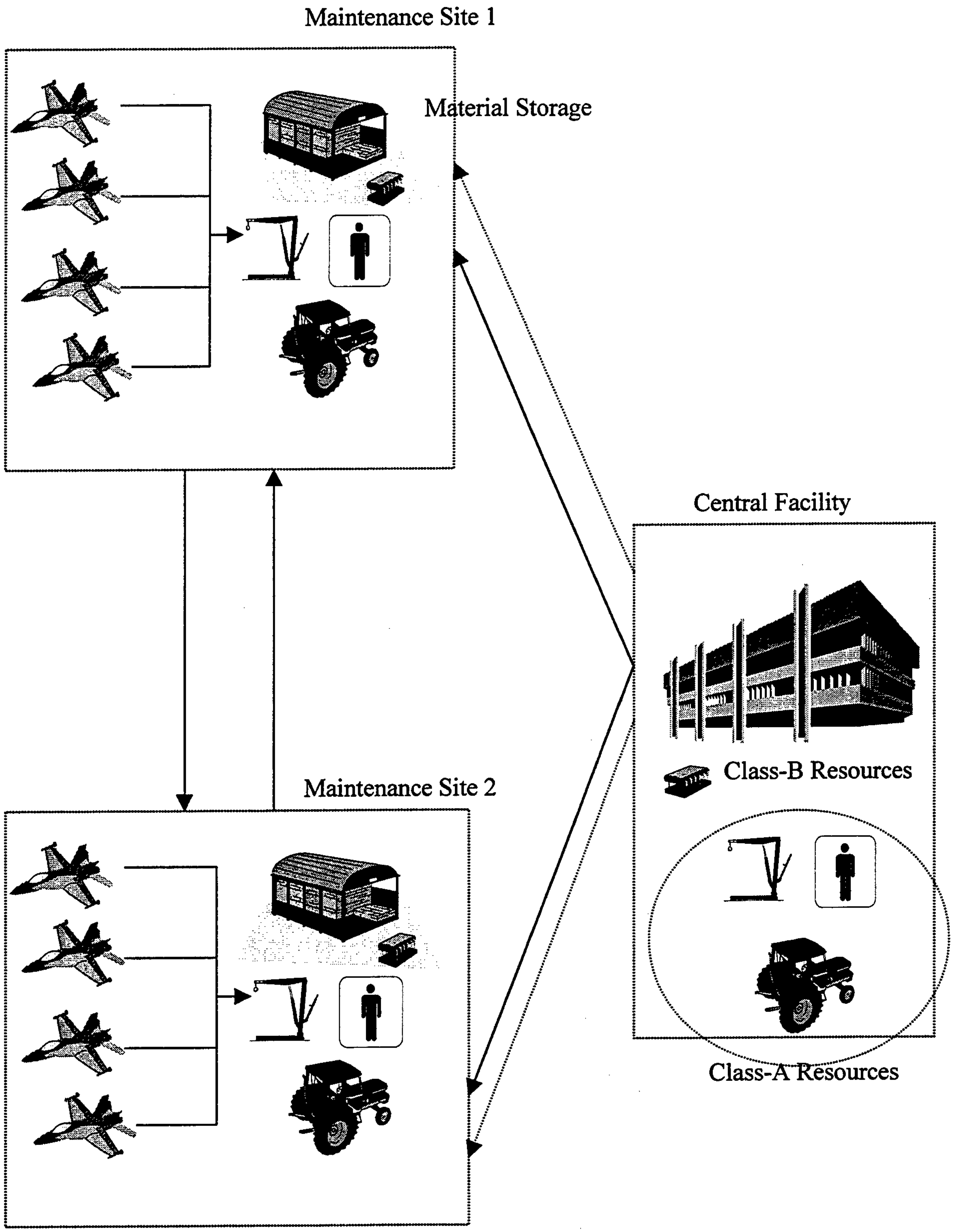
Conceptual Variable Preference Matrix

Table H-1. Preference Matrix

Confirmation Weight factor	WF1	0.3
Frequency-of-use weight factor	WF2	0.5
Assigned-importance weight factor	WF3	0.2

#	V. Group	Consolidated Conceptual Variable	Manpowe(1)	Spare Parts (2)	AGE (3)	Confirm? 3=Y 0=N (4)	(4) * WF1 (5)	Frequency of use (6)	(6)* WF2 (7)	Assigned Importance (8)	(8) * WF3 (9)	Total Score=(5)+(7)+(9)
1	AD	Reliability parameters	1	1	1	3	0.9	3	1.5	3	0.6	3
2	AD	Repair time distributions	1		1	3	0.9	3	1.5	1	0.2	2.6
3	AD	Required resources		1		3	0.9	2	1	3	0.6	2.5
4	AD	Alternative required resources				0	0	1	0.5	1	0.2	0.7
5	AD	Failure criticality	1	1	1	3	0.9	2	1	1	0.2	2.1
6	OP	Flying program	1	1	1	3	0.9	3	1.5	3	0.6	3
7	OP	Alert schedule	1	1	1	3	0.9	2	1	3	0.6	2.5
8	OP	Mission priority				0	0	1	0.5	1	0.2	0.7
9	OP	Mission cancellation criterion				0	0	2	1	1	0.2	1.2
10	OP	Dispersion	1		1	3	0.9	2	1	3	0.6	2.5
11	OP	Probability of retaining munitions/TRAP				0	0	1	0.5	1	0.2	0.7
12	MP	Work shift policy	1			3	0.9	2	1	3	0.6	2.5
13	MP	Required skills level	1	1	1	3	0.9	2	1	2	0.4	2.3
14	MP	Cross training		1		3	0.9	1	0.5	1	0.2	1.6
15	MP	Task organization		1		3	0.9	1	0.5	2	0.4	1.8
16	MP	Task priority		1		3	0.9	2	1	2	0.4	2.3
17	MP	Tasks level	1	1		3	0.9	3	1.5	2	0.4	2.8
18	MP	Preventive inspection schedule	1			3	0.9	1	0.5	2	0.4	1.8
19	SP	Resource availability		1		3	0.9	3	1.5	3	0.6	3
20	SP	Resupply procedure		1		3	0.9	2	1	3	0.6	2.5
21	SP	Cannibalization criterion		1		3	0.9	1	0.5	3	0.6	2
22	SP	Substitutability		1		3	0.9	1	0.5	3	0.6	2
23	SL	Support equipment unscheduled maintenance	1		1	3	0.9	3	1.5	1	0.2	2.6
24	SL	Support equipment periodic servicing	1		1	3	0.9	3	1.5	3	0.6	3
25	SL	Facility maintenance				0	0	3	1.5	1	0.2	1.7
26	E	Minimum weather condition				0	0	3	1.5	3	0.6	2.1
27	E	Weather dependent transit times				0	0	3	1.5	3	0.6	2.1
28	EA	Battle damage				0	0	3	1.5	3	0.6	2.1
29	EA	Combat losses		1		3	0.9	3	1.5	3	0.6	3
30	EA	Base attack damage				0	0	1	0.5	3	0.6	1.1

APPENDIX I
Base Physical Distribution



APPENDIX J

General Computation Method

Step 1: Definition maintenance activities network

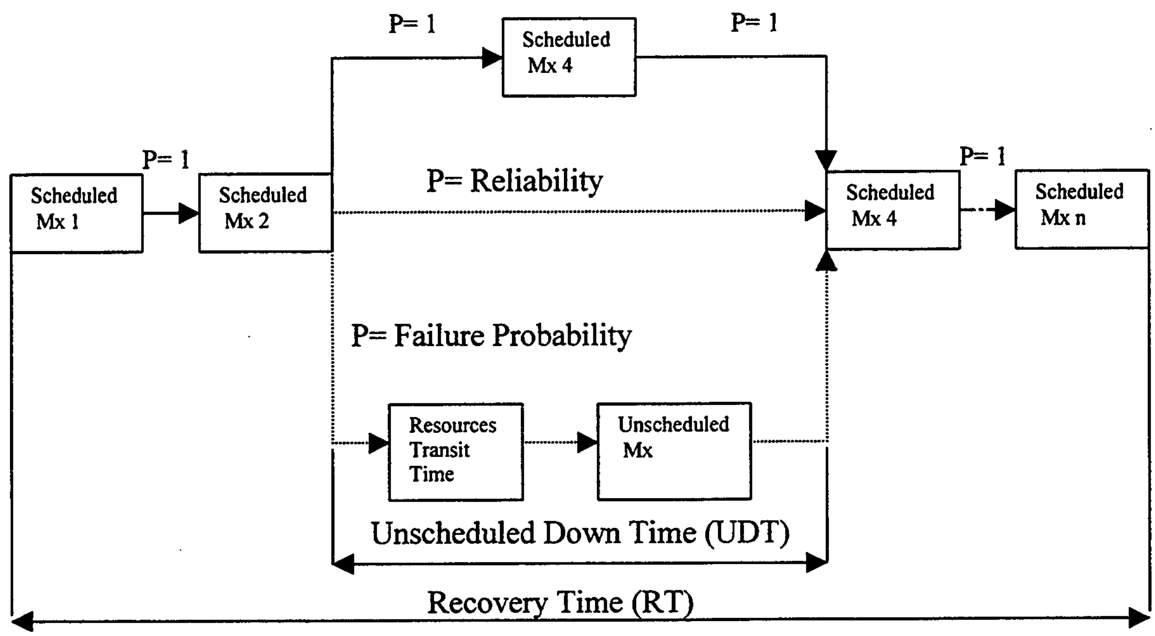


Figure J-1. Maintenance Activities Network for Aircraft Recovery

Step 2: Computation of **Mean Down Time** ($\overline{UDT}$) and **Variance of Down Time** VAR(UDT) at each maintenance site, using a functional probabilistic method.

Step 3: Assuming that Down Time has a lognormal distribution, the completion of the conditional network of activities defined in step 1 is simulated. The arrival of aircraft from the previous mission and their simultaneous recovery to be ready for the next mission is simulated through the generation of completion times for each task (Monte

Carlo approach). For scheduled activities triangular distributions of completion times are used.

Step 4: The simulation of the aircraft recovery process is replicated in order to develop a 95% confidence interval for the mean of the number of aircraft that can be recovered within a given interval *I*. The upper and lower limit of the mean number of aircraft recovered is presented as a function of *I*. This is the output of the model.

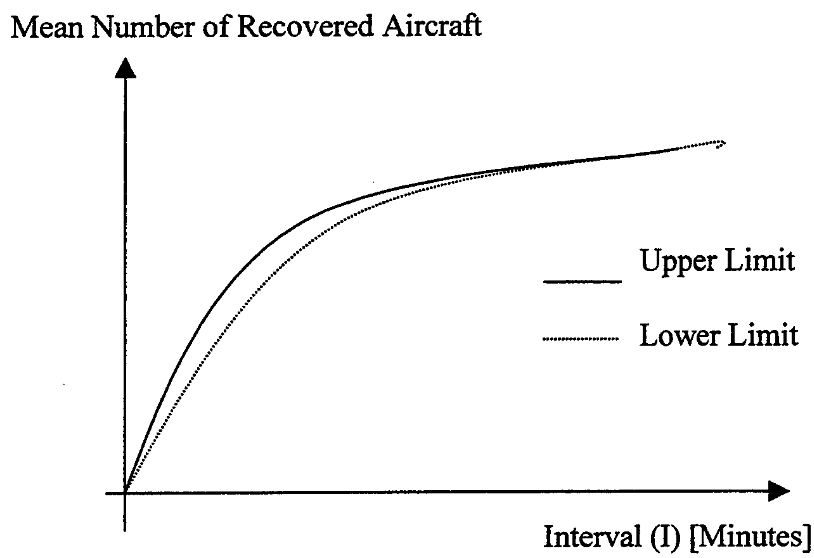
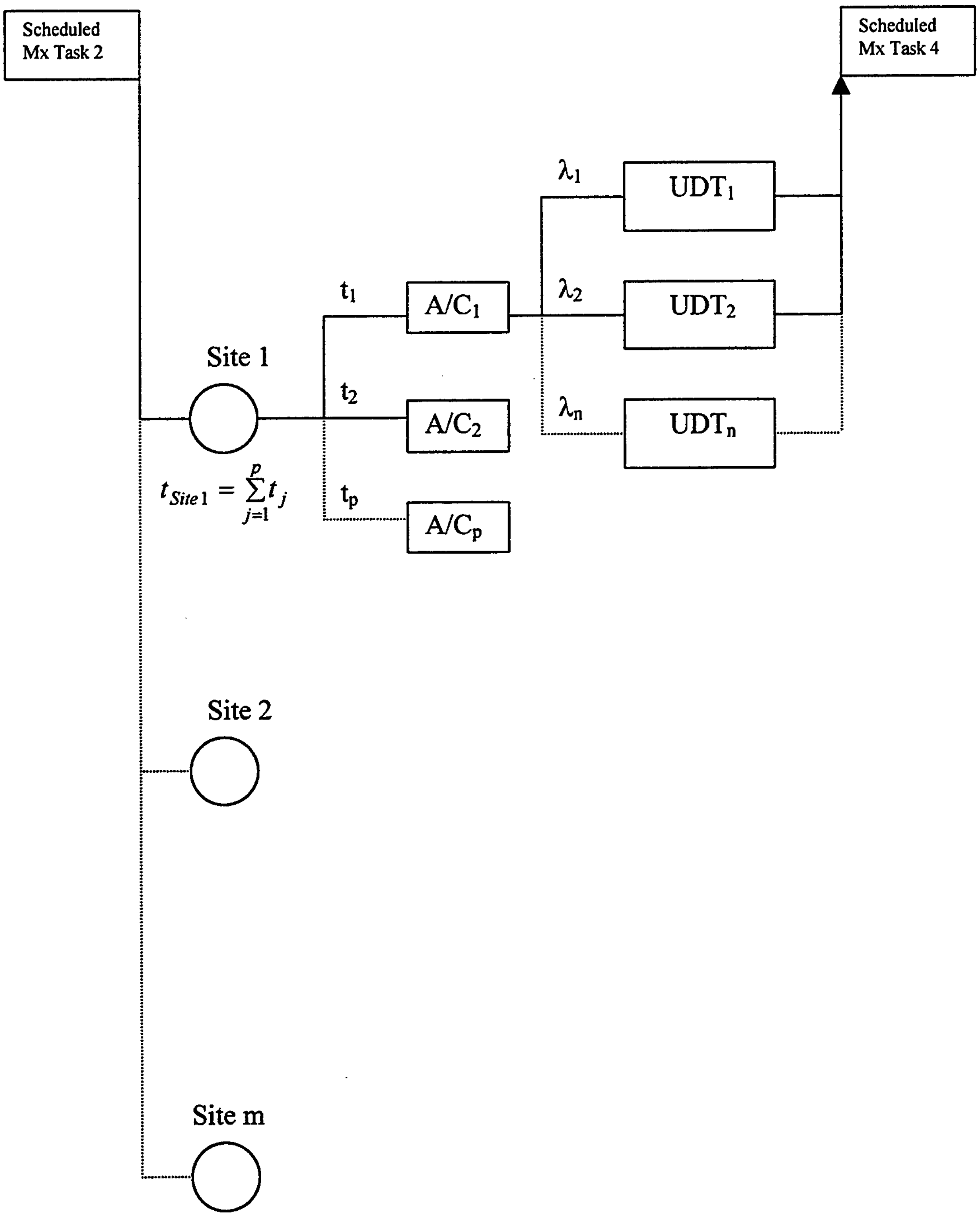


Figure J-2. Model Output

APPENDIX K

Unscheduled Down Time



APPENDIX L

Mean and Variance Computation for Joint Distribution of Independent Random Variables

Problem Statement

Let's say that there are i=1,2,...,k random variables (Z_i) that represent the time to perform a particular task. Each of this random variables has a mean $\overline{Z_i}$ and a variance VAR(Z_i). Each task i occurs with a probability p_i. If the events represented by these random variables are mutually exclusive and exhaustive (i.e. one event must occur but only one can occur at a given time), then:

$$\sum_{i=1}^{k} p_i = 1$$

We are interested in the central tendency and variability parameters of the resulting distribution of time T where T=(Z_1, Z_2, ..., Z_k). This is a joint random variable, with mean $\overline{T}$ and variance VAR(T).

Solution

If the probability of occurrence of each event is independent from the values that the variables can take on, then this problem is analogous to the one presented and solved by Yastan (1968:91). Adopting the same solution and making the due notational changes we conclude that:

$$\overline{T} = \sum_{i=1}^{k} (p_i)(\overline{Z_i}) \tag{24}$$

$$VAR(T) = \sum_{i=1}^{k}(p_i)\left[VAR(Z_i) + \overline{Z_i}^2\right] - \overline{T}^2 \tag{25}$$

If for the sake of notational simplicity, we replace μ_i for $\overline{Z_i}$ and $\overline{\mu_i}$ for $\overline{T}$ in equations (24) and (25), we have:

$$\overline{T} = \sum_{i=1}^{k}(p_i)(\mu_i) = \overline{\mu_i}$$

$$VAR(T) = \sum_{i=1}^{k}(p_i)\left[VAR(Z_i) + \mu_i^2\right] - \overline{\mu_i}^2 \tag{26}$$

Working algebraically with expression (26) we have:

$$VAR(T) = \sum_{i=1}^{k}(p_i)VAR(Z_i) + \sum_{i=1}^{k}(P_i)\mu_i^2 - \overline{\mu_i}^2$$

$$VAR(T) = \sum_{i=1}^{k}(p_i)VAR(Z_i) + \overline{\mu_i^2} - \overline{\mu_i}^2 \tag{27}$$

Applying the identity (28) presented by Bronstein and Semedian (1976:650) in equation (27) we have equation (29):

$$\overline{\mu_i^2} - \overline{\mu_i}^2 = \sum_{i=1}^{k}(p_i)\left(\mu_i - \overline{\mu_i}\right)^2 \tag{28}$$

$$VAR(T) = \sum_{i=1}^{k}(p_i)\left[VAR(Z_i) - \left(\mu_i - \overline{\mu_i}\right)^2\right] \tag{29}$$

Restoring the initial notation in equation (29), we have:

$$VAR(T) = \sum_{i=1}^{k}(p_i)\left[VAR(Z_i) - \left(\overline{Z_i} - \overline{T}\right)^2\right] \tag{30}$$

Summarizing

The central tendency and variability parameters of the resulting distribution of joint distribution (T) can be computed using equation (24) and (30), identical to equations (1) and (2) introduced in Chapter IV:

$$\overline{T} = \sum_{i=1}^{k} (p_i)(\overline{Z_i}) \tag{1}$$

$$VAR(T) = \sum_{i=1}^{k} (p_i)\left[VAR(Z_i) - \left(\overline{Z_i} - \overline{T}\right)^2\right] \tag{3}$$

If the number of event repetitions is large enough, then the observed frequency of occurrence f_i of that event tends towards its probability of occurrence p_i. In this case f_i can replace P_i in equation (24) and (32). And we will have:

$$\overline{T} = \sum_{i=1}^{k} (f_i)(\overline{Z_i}) \tag{2}$$

$$VAR(T) = \sum_{i=1}^{k} (f_i)\left[VAR(Z_i) - \left(\overline{Z_i} - \overline{T}\right)^2\right] \tag{4}$$

APPENDIX M

Data Used for MRET Model Verification Purposes

Operational Variables

Total Number of Aircraft	Sortie Length [hr]	Number of Maintenance sites	Number of Aircraft Per Site
12	2	2	6

Maintenance and Supply Variables

Table M-1. MTBF and Required Resources to Repair Each Critical Failure Mode

Critical Failure Mode	MTBF [hr]	Parts	Personnel	Support Equipment	Test Equipment
1	400	Part1	C2	SE1	TE1
2	400	Part2	C2	SE2	TE2
3	400	Part3	C2	SE1	TE1
4	400	Part4	C2	SE2	TE2
5	400	Part5	C2	SE1	TE1
6	400	Part6	C2	SE2	TE2
7	400	Part7	C2	SE1	TE1
8	400	Part8	C2	SE2	TE2
9	400	Part9	C2	SE1	TE1
10	400	Part10	C2	SE2	TE2

Table M-2. Repair Time for Unscheduled Maintenance Task

Critical Failure Mode	Minimum [Minutes]	Most Frequent [Minutes]	Maximum [Minutes]
1	20	30	40
2	20	30	40
3	20	30	40
4	20	30	40
5	20	30	40
6	20	30	40
7	20	30	40
8	20	30	40
9	40	60	90
10	40	45	60

Table M-3. Transit Times

From	To	Minimum [Minutes]	Most Frequent [Minutes]	Maximum [Minutes]
Site 1	A/C	8	10	12
Site 2	A/C	8	10	12
Site	Site	15	20	35
Central	A/C(Site1)	30	40	50
Central	A/C(Site2)	30	40	50

Table M-4. Minimum Scheduled Task Times as a Function of the Order in which Each Aircraft Receives the Services and the Resource Level [minutes]

	First Aircraft			Second Aircraft			Third Aircraft		
TASK	RL=1	RL=2	RL=3	RL=1	RL=2	RL=3	RL=1	RL=2	RL=3
1	5	5	5	5	5	5	5	5	5
2	10	10	10	12	10	10	14	12	10
3	10	10	10	12	10	10	14	12	10
4	10	10	10	12	10	10	14	12	10
5	20	20	20	25	20	20	30	25	20
6	20	20	20	25	20	20	30	25	20
7	10	10	10	12	10	10	14	12	10
8	5	5	5	5	5	5	5	5	5

Table M-5. Most Frequent Scheduled Task Times as a Function of the Order in which Each Aircraft Receives the Services and the Resource Level [minutes]

	First Aircraft			Second Aircraft			Third Aircraft		
TASK	RL=1	RL=2	RL=3	RL=1	RL=2	RL=3	RL=1	RL=2	RL=3
1	7	7	7	7	7	7	7	7	7
2	15	15	15	17	15	15	19	17	15
3	15	15	15	17	15	15	19	17	15
4	15	15	15	17	15	15	19	17	15
5	25	25	25	30	25	25	35	30	25
6	25	25	25	30	25	25	35	30	25
7	15	15	15	17	15	15	19	17	15
8	7	7	7	7	7	7	7	7	7

Table M-6. Maximum Scheduled Task Times as a Function of the Order in which each Aircraft Receives the Services and the Resource Level.

	First Aircraft			Second Aircraft			Third Aircraft		
TASK	RL=1	RL=2	RL=3	RL=1	RL=2	RL=3	RL=1	RL=2	RL=3
1	10	10	10	10	10	10	10	10	10
2	20	20	20	22	20	20	24	22	20
3	20	20	20	22	20	20	24	22	20
4	20	20	20	22	20	20	24	22	20
5	30	30	30	35	30	30	40	35	30
6	30	30	30	35	30	30	40	35	30
7	20	20	20	22	20	20	24	22	20
8	10	10	10	10	10	10	10	10	10

APPENDIX N

SLAM II Program Code

```
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ARRAY(7,10)/0,1,0,1,0,1,0,1,0,1;
ARRAY(8,10)/0.333,0.333,0.333,0.333,0.333,0.333,0.333,0.333,0.666,0.666;
ARRAY(9,10)/0.5,0.5,0.5,0.5,0.5,0.5,0.5,0.5,1,0.75;
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INTLC,XX(60)=0,XX(61)=0,XX(62)=0,XX(63)=0,XX(64)=0,XX(65)=0,XX(66)=0,XX(67)=0,
XX(68)=0,XX(69)=0,XX(70)=0,XX(71)=0,XX(75)=0;
INTLC,XX(1)=2,XX(2)=2,XX(3)=2,XX(4)=2,XX(5)=2,XX(6)=2,XX(7)=2,XX(8)=2,XX(9)=2,
XX(10)=2;
INTLC,XX(21)=2,XX(22)=2,XX(23)=2,XX(24)=2,XX(24)=2,XX(25)=2,XX(26)=2,XX(27)=2,
XX(28)=2,XX(29)=2,XX(30)=2;
INTLC,XX(11)=6000,XX(12)=6000,XX(13)=6000,XX(14)=6000,XX(15)=6000,XX(16)=6000,
XX(17)=6000,XX(18)=6000,XX(19)=6000,XX(20)=6000;
TIMST,XX(34),BO;
TIMST,XX(80),LE90;
TIMST,XX(81),LE100;
TIMST,XX(82),LE110;
TIMST,XX(83),LE120;
TIMST,XX(84),LE130;
TIMST,XX(85),LE140;
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TIMST,XX(86),LE150;
TIMST,XX(87),LE160;
TIMST,XX(88),LE170;
TIMST,XX(89),LE180;
INITIALIZE,,,Y;
NETWORK;
;FILE MAMBMSNF
      RESOURCE/1,TE2_1(2),6;
      RESOURCE/2,CREW2_1(2),2;
      RESOURCE/3,SE1_1(2),3;
      RESOURCE/4,SE2_1(2),4;
      RESOURCE/5,TE1_1(2),5;
      RESOURCE/7,CREW2_0(2),7;
      RESOURCE/8,SE1_0(2),8;
      RESOURCE/9,SE2_0(2),9;
      RESOURCE/10,TE1_0(2),10;
      RESOURCE/11,TE2_0(2),11;
      RESOURCE/12,CREW2_2(2),12;
      RESOURCE/13,SE1_2(2),13;
      RESOURCE/14,SE2_2(2),14;
      RESOURCE/15,TE1_2(2),15;
      RESOURCE/16,TE2_2(2),16;
;FILE MAMBMSNF
;
AC1   CREATE,12,,1,2000,1;
      ACTIVITY;
ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=1,ATRIB(19)=1,1;
      ACTIVITY,ATRIB(2),,S1;
;
DIST  GOON,1;
      ACTIVITY,,XX(56)+XX(76).EQ.12;
      ACTIVITY,,XX(56)+XX(76).LT.12,TIME;

ASSIGN,XX(1)=ARRAY(2,1),XX(2)=ARRAY(2,2),XX(3)=ARRAY(2,3),XX(4)=ARRAY(2,

4),XX(5)=ARRAY(2,5),XX(6)=ARRAY(2,6),XX(7)=ARRAY(2,7),XX(8)=ARRAY(2,8),XX(
      9)=ARRAY(2,9),XX(10)=ARRAY(2,10),1;
      ACTIVITY;

ASSIGN,XX(21)=ARRAY(11,1),XX(22)=ARRAY(11,2),XX(23)=ARRAY(11,3),XX(24)=

ARRAY(11,4),XX(25)=ARRAY(11,5),XX(26)=ARRAY(11,6),XX(27)=ARRAY(11,7),XX(
      28)=ARRAY(11,8),XX(29)=ARRAY(11,9),XX(30)=ARRAY(11,10),1;
      ACTIVITY,,,TIME;
;
AC2   CREATE,12,,1,2000,1;
      ACTIVITY;
      ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=2,ATRIB(19)=1,1;
      ACTIVITY,ATRIB(2),,S1;
;
B     ASSIGN,ATRIB(4)=XX(31),XX(33)=XX(33)+1,ATRIB(17)=1,1;
      ACTIVITY;
      ASSIGN,XX(31)=0,ATRIB(6)=TNOW,ATRIB(7)=XX(33),2;
      ACTIVITY;
      ACTIVITY,,,TA;
      GOON,1;
      ACTIVITY,,ATRIB(4).EQ.1;
      ACTIVITY,,ATRIB(4).EQ.2,ZAAD;
      ACTIVITY,,ATRIB(4).EQ.3,ZAAF;
      ACTIVITY,,ATRIB(4).EQ.4,ZAAH;
      ACTIVITY,,ATRIB(4).EQ.5,ZAAJ;
```

```
     ACTIVITY,,ATRIB(4).EQ.6,ZAAL;
     ACTIVITY,,ATRIB(4).EQ.7,ZAAN;
     ACTIVITY,,ATRIB(4).EQ.8,ZAAP;
     ACTIVITY,,ATRIB(4).EQ.9,ZAAR;
     ACTIVITY,,ATRIB(4).EQ.10,ZAAT;
     GOON,1;
     ACTIVITY,,XX(1).GT.0;
     ACTIVITY,,XX(1).EQ.0,ZAAB;
     ASSIGN,XX(1)=XX(1)-1,1;
     ACTIVITY,,,SST;
ZAAB ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C1;
ZAAD GOON,1;
     ACTIVITY,,XX(2).GT.0;
     ACTIVITY,,XX(2).EQ.0,ZAAC;
     ASSIGN,XX(2)=XX(2)-1,1;
     ACTIVITY,,,SST;
ZAAC ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C2;
ZAAF GOON,1;
     ACTIVITY,,XX(3).GT.0;
     ACTIVITY,,XX(3).EQ.0,ZAAE;
     ASSIGN,XX(3)=XX(3)-1,1;
     ACTIVITY,,,SST;
ZAAE ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C3;
ZAAH GOON,1;
     ACTIVITY,,XX(4).GT.0;
     ACTIVITY,,XX(4).EQ.0,ZAAG;
     ASSIGN,XX(4)=XX(4)-1,1;
     ACTIVITY,,,SST;
ZAAG ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C4;
ZAAJ GOON,1;
     ACTIVITY,,XX(5).GT.0;
     ACTIVITY,,XX(5).EQ.0,ZAAI;
     ASSIGN,XX(5)=XX(5)-1,1;
     ACTIVITY,,,SST;
ZAAI ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C5;
ZAAL GOON,1;
     ACTIVITY,,XX(6).GT.0;
     ACTIVITY,,XX(6).EQ.0,ZAAK;
     ASSIGN,XX(6)=XX(6)-1,1;
     ACTIVITY,,,SST;
ZAAK ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C6;
ZAAN GOON,1;
     ACTIVITY,,XX(7).GT.0;
     ACTIVITY,,XX(7).EQ.0,ZAAM;
     ASSIGN,XX(7)=XX(7)-1,1;
     ACTIVITY,,,SST;
ZAAM ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C7;
ZAAP GOON,1;
     ACTIVITY,,XX(8).GT.0;
     ACTIVITY,,XX(8).EQ.0,ZAAO;
     ASSIGN,XX(8)=XX(8)-1,1;
     ACTIVITY,,,SST;
ZAAO ASSIGN,ATRIB(15)=1,1;
     ACTIVITY,,,C8;
```

```
ZAAR  GOON,1;
      ACTIVITY,,XX(9).GT.0;
      ACTIVITY,,XX(9).EQ.0,ZAAQ;
      ASSIGN,XX(9)=XX(9)-1,1;
      ACTIVITY,,,SST;
ZAAQ  ASSIGN,ATRIB(15)=1,1;
      ACTIVITY,,,C9;
ZAAT  GOON,1;
      ACTIVITY,,XX(10).GT.0;
      ACTIVITY,,XX(10).EQ.0,ZAAS;
      ASSIGN,XX(10)=XX(10)-1,1;
      ACTIVITY,,,SST;
ZAAS  ASSIGN,ATRIB(15)=1,1;
      ACTIVITY,,,C10;
;
C1    GOON,1;
      ACTIVITY,,XX(11).GT.0;
      ACTIVITY,,XX(11).EQ.0,ZAAU;
      ASSIGN,XX(11)=XX(11)-1,1;
      ACTIVITY;
      GOON,1;
      ACTIVITY,,ATRIB(15).EQ.1,LST;
      ACTIVITY,,ATRIB(15).EQ.2,LST2;
ZAAU  ASSIGN,XX(34)=XX(34)+1,1;
      ACTIVITY,,,END;
;
F     ASSIGN,XX(31)=XX(31)+1,1;
      ACTIVITY;
      ASSIGN,ATRIB(3)=ARRAY(1,XX(31)),ATRIB(5)=EXPON(ATRIB(3)),1;
      ACTIVITY,,ATRIB(5).LE.ATRIB(2),B;
      ACTIVITY,,ATRIB(5).GT.ATRIB(2);
      GOON,1;
      ACTIVITY,,XX(31).EQ.XX(32);
      ACTIVITY,,XX(31).LT.XX(32),F;
      ASSIGN,XX(31)=0,1;
      ACTIVITY,,,SM61;
;
AC3   CREATE,12,,1,2000,1;
      ACTIVITY;
      ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=3,ATRIB(19)=1,1;
      ACTIVITY,ATRIB(2),,S1;
;
C2    GOON,1;
      ACTIVITY,,XX(12).GT.0;
      ACTIVITY,,XX(12).EQ.0,ZAAV;
      ASSIGN,XX(12)=XX(12)-1,1;
      ACTIVITY;
      GOON,1;
      ACTIVITY,,ATRIB(15).EQ.1,LST;
      ACTIVITY,,ATRIB(15).EQ.2,LST2;
ZAAV  ASSIGN,XX(34)=XX(34)+1,1;
      ACTIVITY,,,END;
;
AC4   CREATE,12,,1,2000,1;
      ACTIVITY;
      ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=4,ATRIB(19)=2,1;
      ACTIVITY,ATRIB(2),,S1;
;
C3    GOON,1;
      ACTIVITY,,XX(13).GT.0;
      ACTIVITY,,XX(13).EQ.0,ZAAW;
```

```
          ASSIGN,XX(13)=XX(13)-1,1;
          ACTIVITY;
          GOON,1;
          ACTIVITY,,ATRIB(15).EQ.1,LST;
          ACTIVITY,,ATRIB(15).EQ.2,LST2;
ZAAW      ASSIGN,XX(34)=XX(34)+1,1;
          ACTIVITY,,,END;
;
DATA      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.1.5;
            ACTIVITY,,TNOW-ATRIB(20).GT.1.5,ZABF;
          ASSIGN,XX(90)=XX(90)+1,1;
          ACTIVITY,,,XX;
ZABF      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.1.6667;
          ACTIVITY,,TNOW-ATRIB(20).GT.1.6667,ZABE;
          ASSIGN,XX(91)=XX(91)+1,1;
          ACTIVITY,,,XX;
ZABE      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.1.8333;
          ACTIVITY,,TNOW-ATRIB(20).GT.1.8333,ZABD;
          ASSIGN,XX(92)=XX(92)+1,1;
          ACTIVITY,,,XX;
ZABD      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.2;
          ACTIVITY,,TNOW-ATRIB(20).GT.2,ZABC;
          ASSIGN,XX(93)=XX(93)+1,1;
          ACTIVITY,,,XX;
ZABC      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.2.1667;
          ACTIVITY,,TNOW-ATRIB(20).GT.2.1667,ZABB;
          ASSIGN,XX(94)=XX(94)+1,1;
          ACTIVITY,,,XX;
ZABB      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.2.3333;
          ACTIVITY,,TNOW-ATRIB(20).GT.2.3333,ZABA;
          ASSIGN,XX(95)=XX(95)+1,1;
          ACTIVITY,,,XX;
ZABA      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.2.5;
          ACTIVITY,,TNOW-ATRIB(20).GT.2.5,ZAAZ;
          ASSIGN,XX(95)=XX(95)+1,1;
          ACTIVITY,,,XX;
ZAAZ      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.2.6667;
          ACTIVITY,,TNOW-ATRIB(20).GT.2.667,ZAAY;
          ASSIGN,XX(95)=XX(95)+1,1;
          ACTIVITY,,,XX;
ZAAY      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.2.8333;
          ACTIVITY,,TNOW-ATRIB(20).GT.2.8333,ZAAX;
          ASSIGN,XX(95)=XX(95)+1,1;
          ACTIVITY,,,XX;
ZAAX      GOON,1;
          ACTIVITY,,TNOW-ATRIB(20).LE.3;
          ACTIVITY,,TNOW-ATRIB(20).GT.3,XX;
          ASSIGN,XX(95)=XX(95)+1,1;
          ACTIVITY,,,XX;
XX        GOON,1;
          ACTIVITY,,XX(56)+XX(76).EQ.12;
          ACTIVITY,,XX(56)+XX(76).LT.12,END;
```

```
ASSIGN,XX(80)=XX(90),XX(81)=XX(91)+XX(90),XX(82)=XX(92)+XX(91)+XX(90),XX(
83)=XX(93)+XX(92)+XX(91)+XX(90),XX(84)=XX(94)+XX(93)+XX(92)+XX(91)+XX(90),
XX(85)=XX(95)+XX(94)+XX(93)+XX(92)+XX(91)+XX(90),XX(86)=XX(96)+XX(95)+XX(
94)+XX(93)+XX(92)+XX(91)+XX(90),XX(87)=XX(97)+XX(96)+XX(95)+XX(94)+XX(93)+
           XX(92)+XX(91)+XX(90),1;
           ACTIVITY;
           ASSIGN,XX(88)=XX(98)+XX(87),XX(89)=XX(99)+XX(88),1;
           ACTIVITY;
ASSIGN,XX(90)=0,XX(91)=0,XX(92)=0,XX(93)=0,XX(94)=0,XX(95)=0,XX(96)=0,XX(
           97)=0,XX(98)=0,XX(99)=0,XX(56)=0,XX(76)=0,1;
           ACTIVITY,,,END;
     ;
     AC5   CREATE,12,,1,2000,1;
           ACTIVITY;
           ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=5,ATRIB(19)=2,1;
           ACTIVITY,ATRIB(2),,S1;
     ;
     C4    GOON,1;
           ACTIVITY,,XX(14).GT.0;
           ACTIVITY,,XX(14).EQ.0,ZABG;
           ASSIGN,XX(14)=XX(14)-1,1;
           ACTIVITY;
           GOON,1;
           ACTIVITY,,ATRIB(15).EQ.1,LST;
           ACTIVITY,,ATRIB(15).EQ.2,LST2;
     ZABG  ASSIGN,XX(34)=XX(34)+1,1;
           ACTIVITY,,,END;
     ;
     AC6   CREATE,12,,1,2000,1;
           ACTIVITY;
      ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=6,ATRIB(19)=2,1;
           ACTIVITY,ATRIB(2),,S1;
     ;
     C5    GOON,1;
           ACTIVITY,,XX(15).GT.0;
           ACTIVITY,,XX(15).EQ.0,ZABH;
           ASSIGN,XX(15)=XX(15)-1,1;
           ACTIVITY;
           GOON,1;
           ACTIVITY,,ATRIB(15).EQ.1,LST;
           ACTIVITY,,ATRIB(15).EQ.2,LST2;
     ZABH  ASSIGN,XX(34)=XX(34)+1,1;
           ACTIVITY,,,END;
     ;
     C6    GOON,1;
           ACTIVITY,,XX(16).GT.0;
           ACTIVITY,,XX(16).EQ.0,ZABI;
           ASSIGN,XX(16)=XX(16)-1,1;
           ACTIVITY;
           GOON,1;
           ACTIVITY,,ATRIB(15).EQ.1,LST;
           ACTIVITY,,ATRIB(15).EQ.2,LST2;
     ZABI  ASSIGN,XX(34)=XX(34)+1,1;
           ACTIVITY,,,END;
     ;
     TA    GOON,3;
```

```
        ACTIVITY,,ARRAY(3,ATRIB(4)).EQ.1;
        ACTIVITY,,ARRAY(4,ATRIB(4)).EQ.1,ZABL;
        ACTIVITY,,ARRAY(5,ATRIB(4)).EQ.1,ZABN;
        ACTIVITY,,ARRAY(6,ATRIB(4)).EQ.1,ZABP;
        ACTIVITY,,ARRAY(7,ATRIB(4)).EQ.1,ZABR;
        GOON,1;
        ACTIVITY,,NNRSC(CREW2_1).GT.0;
        ACTIVITY,,NNRSC(CREW2_1).EQ.0,ZABJ;
        AWAIT(2),CREW2_1,,1;
        ACTIVITY;
        ASSIGN,ATRIB(10)=-1,1;
        ACTIVITY,,,SRT;
ZABJ    ASSIGN,ATRIB(16)=1,1;
        ACTIVITY,,,CR1;
ZABL    GOON,1;
        ACTIVITY,,NNRSC(SE1_1).GT.0;
        ACTIVITY,,NNRSC(SE1_1).EQ.0,ZABK;
        AWAIT(3),SE1_1,,1;
        ACTIVITY;
        ASSIGN,ATRIB(11)=-1,1;
        ACTIVITY,,,SRT;
ZABK    ASSIGN,ATRIB(16)=1,1;
        ACTIVITY,,,CR2;
ZABN    GOON,1;
        ACTIVITY,,NNRSC(SE2_1).GT.0;
        ACTIVITY,,NNRSC(SE2_1).EQ.0,ZABM;
        AWAIT(4),SE2_1,,1;
        ACTIVITY;
        ASSIGN,ATRIB(12)=-1,1;
        ACTIVITY,,,SRT;
ZABM    ASSIGN,ATRIB(16)=1,1;
        ACTIVITY,,,CR3;
ZABP    GOON,1;
        ACTIVITY,,NNRSC(TE1_1).GT.0;
        ACTIVITY,,NNRSC(TE1_1).EQ.0,ZABO;
        AWAIT(5),TE1_1,,1;
        ACTIVITY;
        ASSIGN,ATRIB(13)=-1,1;
        ACTIVITY,,,SRT;
ZABO    ASSIGN,ATRIB(16)=1,1;
        ACTIVITY,,,CR4;
ZABR    GOON,1;
        ACTIVITY,,NNRSC(TE2_1).GT.0;
        ACTIVITY,,NNRSC(TE2_1).EQ.0,ZABQ;
        AWAIT(6),TE2_1,,1;
        ACTIVITY;
        ASSIGN,ATRIB(14)=-1,1;
        ACTIVITY,,,SRT;
ZABQ    ASSIGN,ATRIB(16)=1,1;
        ACTIVITY,,,CR5;
;
C7      GOON,1;
        ACTIVITY,,XX(17).GT.0;
        ACTIVITY,,XX(17).EQ.0,ZABS;
        ASSIGN,XX(17)=XX(17)-1,1;
        ACTIVITY;
        GOON,1;
        ACTIVITY,,ATRIB(15).EQ.1,LST;
        ACTIVITY,,ATRIB(15).EQ.2,LST2;
ZABS    ASSIGN,XX(34)=XX(34)+1,1;
        ACTIVITY,,,END;
```

```
;
C8      GOON,1;
        ACTIVITY,,XX(18).GT.0;
        ACTIVITY,,XX(18).EQ.0,ZABT;
        ASSIGN,XX(18)=XX(18)-1,1;
        ACTIVITY;
        GOON,1;
        ACTIVITY,,ATRIB(15).EQ.1,LST;
        ACTIVITY,,ATRIB(15).EQ.2,LST2;
ZABT    ASSIGN,XX(34)=XX(34)+1,1;
        ACTIVITY,,,END;
;
C9      GOON,1;
        ACTIVITY,,XX(19).GT.0;
        ACTIVITY,,XX(19).EQ.0,ZABU;
        ASSIGN,XX(19)=XX(19)-1,1;
        ACTIVITY;
        GOON,1;
        ACTIVITY,,ATRIB(15).EQ.1,LST;
        ACTIVITY,,ATRIB(15).EQ.2,LST2;
ZABU    ASSIGN,XX(34)=XX(34)+1,1;
        ACTIVITY,,,END;
;
SST     GOON,1;
        ACTIVITY,TRIAG(0.1333,0.1666,0.2);
ZACH    BATCH,12/7,4,,LAST/10,11,12,13,14,ALL(8),1;
        ACTIVITY;

ASSIGN,XX(35)=ARRAY(8,ATRIB(4)),XX(36)=ARRAY(9,ATRIB(4)),XX(37)=ARRAY(10,
        ATRIB(4)),1;
        ACTIVITY,TRIAG(XX(35),XX(36),XX(37));
        COLCT,INT(6),DOWN_T_1,,1;
        ACTIVITY;
        UNBATCH,8,1;
        ACTIVITY,,ATRIB(10).EQ.-1;
        ACTIVITY,,ATRIB(10).EQ.-2,ZABW;
        ACTIVITY,,ATRIB(11).EQ.-1,ZABX;
        ACTIVITY,,ATRIB(11).EQ.-2,ZABY;
        ACTIVITY,,ATRIB(12).EQ.-1,ZABZ;
        ACTIVITY,,ATRIB(12).EQ.-2,ZACA;
        ACTIVITY,,ATRIB(13).EQ.-1,ZACB;
        ACTIVITY,,ATRIB(13).EQ.-2,ZACC;
        ACTIVITY,,ATRIB(14).EQ.-1,ZACD;
        ACTIVITY,,ATRIB(14).EQ.-2,ZACE;
        ACTIVITY,,ATRIB(17).EQ.1,ZACF;
        FREE,CREW2_1,1;
        ACTIVITY;
ZABV    BATCH,2/7,3,,,,1;
        ACTIVITY,,,SM61;
ZABW    FREE,CREW2_0,1;
        ACTIVITY,,,ZABV;
ZABX    FREE,SE1_1,1;
        ACTIVITY,,,ZABV;
ZABY    FREE,SE1_0,1;
        ACTIVITY,,,ZABV;
ZABZ    FREE,SE2_1,1;
        ACTIVITY,,,ZABV;
ZACA    FREE,SE2_0,1;
        ACTIVITY,,,ZABV;
ZACB    FREE,TE1_1,1;
        ACTIVITY,,,ZABV;
```

```
ZACC  FREE,TE1_0,1;
      ACTIVITY,,,ZABV;
ZACD  FREE,TE2_1,1;
      ACTIVITY,,,ZABV;
ZACE  FREE,TE2_0,1;
      ACTIVITY,,,ZABV;
ZACF  TERMINATE;
;
C10   GOON,1;
      ACTIVITY,,XX(20).GT.0;
      ACTIVITY,,XX(20).EQ.0,ZACG;
      ASSIGN,XX(20)=XX(20)-1,1;
      ACTIVITY;
      GOON,1;
      ACTIVITY,,ATRIB(15).EQ.1,LST;
      ACTIVITY,,ATRIB(15).EQ.2,LST2;
ZACG  ASSIGN,XX(34)=XX(34)+1,1;
      ACTIVITY,,,END;
;
LST   GOON,1;
      ACTIVITY,TRIAG(0.5,0.6666,0.8333),,ZACH;
;
SRT   GOON,1;
      ACTIVITY,TRIAG(0.1333,0.1666,0.2),,ZACH;
;
TIME  GOON,1;
      ACTIVITY;
      COLCT,INT(20),NON_F,,1;
      ACTIVITY,,,DATA;
;
END   TERMINATE;
;
LRT   GOON,1;
      ACTIVITY,TRIAG(0.5,0.6666,0.8333),,ZACH;
;
ITT   GOON,1;
      ACTIVITY,TRIAG(0.25,.3333,0.5833),,ZACH;
;
AC7   CREATE,12,,1,2000,1;
      ACTIVITY;
      ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=7,ATRIB(19)=1,1;
      ACTIVITY,ATRIB(2),,S2;
;
CR1   GOON,1;
      ACTIVITY,,NNRSC(CREW2_0).GT.0;
      ACTIVITY,,NNRSC(CREW2_0).EQ.0,ZACK;
ZACJ  AWAIT(7),CREW2_0,,1;
      ACTIVITY;
      ASSIGN,ATRIB(10)=-2,1;
      ACTIVITY;
      GOON,1;
      ACTIVITY,,ATRIB(16).EQ.1;
      ACTIVITY,,ATRIB(16).EQ.2,ZACI;
      GOON,1;
      ACTIVITY,,ATRIB(9).EQ.1,ITT;
      ACTIVITY,,ATRIB(9).EQ.0,LRT;
ZACI  GOON,1;
      ACTIVITY,,ATRIB(9).EQ.1,ITT2;
      ACTIVITY,,ATRIB(9).EQ.0,LRT2;
ZACK  ASSIGN,ATRIB(9)=1,1;
      ACTIVITY,,,ZACJ;
```

```
;
AC8   CREATE,12,,1,2000,1;
      ACTIVITY;
      ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=8,ATRIB(19)=1,1;
      ACTIVITY,ATRIB(2),,S2;
;
AC9   CREATE,12,,1,2000,1;
      ACTIVITY;
      ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=9,ATRIB(19)=1,1;
      ACTIVITY,ATRIB(2),,S2;
;
B2    ASSIGN,ATRIB(4)=XX(38),XX(33)=XX(33)+1,ATRIB(17)=1,1;
      ACTIVITY;
      ASSIGN,XX(38)=0,ATRIB(6)=TNOW,ATRIB(7)=XX(33),2;
      ACTIVITY;
      ACTIVITY,,,TA2;
      GOON,1;
      ACTIVITY,,ATRIB(4).EQ.1;
      ACTIVITY,,ATRIB(4).EQ.2,ZACN;
      ACTIVITY,,ATRIB(4).EQ.3,ZACP;
      ACTIVITY,,ATRIB(4).EQ.4,ZACR;
      ACTIVITY,,ATRIB(4).EQ.5,ZACT;
      ACTIVITY,,ATRIB(4).EQ.6,ZACV;
      ACTIVITY,,ATRIB(4).EQ.7,ZACX;
      ACTIVITY,,ATRIB(4).EQ.8,ZACZ;
      ACTIVITY,,ATRIB(4).EQ.9,ZADB;
      ACTIVITY,,ATRIB(4).EQ.10,ZADD;
      GOON,1;
      ACTIVITY,,XX(21).GT.0;
      ACTIVITY,,XX(21).EQ.0,ZACL;
      ASSIGN,XX(21)=XX(21)-1,1;
      ACTIVITY,,,SST2;
ZACL  ASSIGN,ATRIB(15)=2,1;
      ACTIVITY,,,C1;
ZACN  GOON,1;
      ACTIVITY,,XX(22).GT.0;
      ACTIVITY,,XX(22).EQ.0,ZACM;
      ASSIGN,XX(22)=XX(22)-1,1;
      ACTIVITY,,,SST2;
ZACM  ASSIGN,ATRIB(15)=2,1;
      ACTIVITY,,,C2;
ZACP  GOON,1;
      ACTIVITY,,XX(23).GT.0;
      ACTIVITY,,XX(23).EQ.0,ZACO;
      ASSIGN,XX(23)=XX(23)-1,1;
      ACTIVITY,,,SST2;
ZACO  ASSIGN,ATRIB(15)=2,1;
      ACTIVITY,,,C3;
ZACR  GOON,1;
      ACTIVITY,,XX(24).GT.0;
      ACTIVITY,,XX(24).EQ.0,ZACQ;
      ASSIGN,XX(24)=XX(24)-1,1;
      ACTIVITY,,,SST2;
ZACQ  ASSIGN,ATRIB(15)=2,1;
      ACTIVITY,,,C4;
ZACT  GOON,1;
      ACTIVITY,,XX(25).GT.0;
      ACTIVITY,,XX(25).EQ.0,ZACS;
      ASSIGN,XX(25)=XX(25)-1,1;
      ACTIVITY,,,SST2;
ZACS  ASSIGN,ATRIB(15)=2,1;
```

```
        ACTIVITY,,,C5;
ZACV    GOON,1;
        ACTIVITY,,XX(26).GT.0;
        ACTIVITY,,XX(26).EQ.0,ZACU;
        ASSIGN,XX(26)=XX(26)-1,1;
        ACTIVITY,,,SST2;
ZACU    ASSIGN,ATRIB(15)=2,1;
        ACTIVITY,,,C6;
ZACX    GOON,1;
        ACTIVITY,,XX(27).GT.0;
        ACTIVITY,,XX(27).EQ.0,ZACW
        ASSIGN,XX(27)=XX(27)-1,1;
        ACTIVITY,,,SST2;
ZACW    ASSIGN,ATRIB(15)=2,1;
        ACTIVITY,,,C7;
ZACZ    GOON,1;
        ACTIVITY,,XX(28).GT.0;
        ACTIVITY,,XX(28).EQ.0,ZACY;
        ASSIGN,XX(28)=XX(28)-1,1;
        ACTIVITY,,,SST2;
ZACY    ASSIGN,ATRIB(15)=2,1;
        ACTIVITY,,,C8;
ZADB    GOON,1;
        ACTIVITY,,XX(29).GT.0;
        ACTIVITY,,XX(29).EQ.0,ZADA;
        ASSIGN,XX(29)=XX(29)-1,1;
        ACTIVITY,,,SST2;
ZADA    ASSIGN,ATRIB(15)=2,1;
        ACTIVITY,,,C9;
ZADD    GOON,1;
        ACTIVITY,,XX(30).GT.0;
        ACTIVITY,,XX(30).EQ.0,ZADC;
        ASSIGN,XX(30)=XX(30)-1,1;
        ACTIVITY,,,SST2;
ZADC    ASSIGN,ATRIB(15)=2,1;
        ACTIVITY,,,C10;
;
CR2     GOON,1;
        ACTIVITY,,NNRSC(SE1_0).GT.0;
        ACTIVITY,,NNRSC(SE1_0).EQ.0,ZADG;
ZADF    AWAIT(8),SE1_0,,1;
        ACTIVITY;
        ASSIGN,ATRIB(11)=-2,1;
        ACTIVITY;
IRT     GOON,1;
        ACTIVITY,,ATRIB(16).EQ.1;
        ACTIVITY,,ATRIB(16).EQ.2,ZADE;
        GOON,1;
        ACTIVITY,,ATRIB(9).EQ.1,ITT;
        ACTIVITY,,ATRIB(9).EQ.0,LRT;
ZADE    GOON,1;
        ACTIVITY,,ATRIB(9).EQ.1,ITT2;
        ACTIVITY,,ATRIB(9).EQ.0,LRT2;
ZADG    ASSIGN,ATRIB(9)=1,1;
        ACTIVITY,,,ZADF;
;
AC10    CREATE,12,,1,2000,1;
        ACTIVITY;
        ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=10,ATRIB(19)=2,1;
        ACTIVITY,ATRIB(2),,S2;
;
```

```
F2     ASSIGN,XX(38)=XX(38)+1,1;
       ACTIVITY;
       ASSIGN,ATRIB(3)=ARRAY(1,XX(38)),ATRIB(5)=EXPON(ATRIB(3)),1;
       ACTIVITY,,ATRIB(5).LE.ATRIB(2),B2;
       ACTIVITY,,ATRIB(5).GT.ATRIB(2);
       GOON,1;
       ACTIVITY,,XX(38).EQ.XX(32);
       ACTIVITY,,XX(38).LT.XX(32),F2;
       ASSIGN,XX(38)=0,1;
       ACTIVITY,,,SM62;
;
AC11   CREATE,12,,1,2000,1;
       ACTIVITY;
       ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=11,ATRIB(19)=2,1;
       ACTIVITY,ATRIB(2),,S2;
;
AC12   CREATE,12,,1,2000,1;
       ACTIVITY;
       ASSIGN,ATRIB(2)=UNFRM(1.9,2.1),ATRIB(18)=12,ATRIB(19)=2,1;
       ACTIVITY,ATRIB(2),,S2;
;
CR3    GOON,1;
       ACTIVITY,,NNRSC(SE2_0).GT.0;
       ACTIVITY,,NNRSC(SE2_0).EQ.0,ZADJ;
ZADI   AWAIT(9),SE2_0,,1;
       ACTIVITY;
       ASSIGN,ATRIB(12)=-2,1;
       ACTIVITY;
       GOON,1;
       ACTIVITY,,ATRIB(16).EQ.1;
       ACTIVITY,,ATRIB(16).EQ.2,ZADH;
       GOON,1;
       ACTIVITY,,ATRIB(9).EQ.1,ITT;
       ACTIVITY,,ATRIB(9).EQ.0,LRT;
ZADH   GOON,1;
       ACTIVITY,,ATRIB(9).EQ.1,ITT2;
       ACTIVITY,,ATRIB(9).EQ.0,LRT2;
ZADJ   ASSIGN,ATRIB(9)=1,1;
       ACTIVITY,,,ZADI;
;
TA2    GOON,3;
       ACTIVITY,,ARRAY(3,ATRIB(4)).EQ.1;
       ACTIVITY,,ARRAY(4,ATRIB(4)).EQ.1,ZADM;
       ACTIVITY,,ARRAY(5,ATRIB(4)).EQ.1,ZADO;
       ACTIVITY,,ARRAY(6,ATRIB(4)).EQ.1,ZADQ;
       ACTIVITY,,ARRAY(7,ATRIB(4)).EQ.1,ZADS;
       GOON,1;
       ACTIVITY,,NNRSC(CREW2_2).GT.0;
       ACTIVITY,,NNRSC(CREW2_2).EQ.0,ZADK;
       AWAIT(12),CREW2_2,,1;
       ACTIVITY;
       ASSIGN,ATRIB(10)=-1,1;
       ACTIVITY,,,SRT2;
ZADK   ASSIGN,ATRIB(16)=2,1;
       ACTIVITY,,,CR1;
ZADM   GOON,1;
       ACTIVITY,,NNRSC(SE1_2).GT.0;
       ACTIVITY,,NNRSC(SE1_2).EQ.0,ZADL;
       AWAIT(13),SE1_2,,1;
       ACTIVITY;
       ASSIGN,ATRIB(11)=-1,1;
```

```
          ACTIVITY,,,SRT2;
   ZADL   ASSIGN,ATRIB(16)=2,1;
          ACTIVITY,,,CR2;
   ZADO   GOON,1;
          ACTIVITY,,NNRSC(SE2_2).GT.0;
          ACTIVITY,,NNRSC(SE2_2).EQ.0,ZADN;
          AWAIT(14),SE2_2,,1;
          ACTIVITY;
          ASSIGN,ATRIB(12)=-1,1;
          ACTIVITY,,,SRT2;
   ZADN   ASSIGN,ATRIB(16)=2,1;
          ACTIVITY,,,CR3;
   ZADQ   GOON,1;
          ACTIVITY,,NNRSC(TE1_2).GT.0;
          ACTIVITY,,NNRSC(TE1_2).EQ.0,ZADP;
          AWAIT(15),TE1_2,,1;
          ACTIVITY;
          ASSIGN,ATRIB(13)=-1,1;
          ACTIVITY,,,SRT2;
   ZADP   ASSIGN,ATRIB(16)=2,1;
          ACTIVITY,,,CR4;
   ZADS   GOON,1;
          ACTIVITY,,NNRSC(TE2_2).GT.0;
          ACTIVITY,,NNRSC(TE2_2).EQ.0,ZADR;
          AWAIT(16),TE2_2,,1;
          ACTIVITY;
          ASSIGN,ATRIB(14)=-1,1;
          ACTIVITY,,,SRT2;
   ZADR   ASSIGN,ATRIB(16)=2,1;
          ACTIVITY,,,CR5;
   ;
   CR4    GOON,1;
          ACTIVITY,,NNRSC(TE1_0).GT.0;
          ACTIVITY,,NNRSC(TE1_0).EQ.0,ZADV;
   ZADU   AWAIT(10),TE1_0,,1;
          ACTIVITY;
          ASSIGN,ATRIB(13)=-2,1;
          ACTIVITY;
          GOON,1;
          ACTIVITY,,ATRIB(16).EQ.1;
          ACTIVITY,,ATRIB(16).EQ.2,ZADT;
          GOON,1;
          ACTIVITY,,ATRIB(9).EQ.1,ITT;
          ACTIVITY,,ATRIB(9).EQ.0,LRT;
   ZADT   GOON,1;
          ACTIVITY,,ATRIB(9).EQ.1,ITT2;
          ACTIVITY,,ATRIB(9).EQ.0,LRT2;
   ZADV   ASSIGN,ATRIB(9)=1,1;
          ACTIVITY,,,ZADU;
   ;
   CR5    GOON,1;
          ACTIVITY,,NNRSC(TE2_0).GT.0;
          ACTIVITY,,NNRSC(TE2_0).EQ.0,ZADY;
   ZADX   AWAIT(11),TE2_0,,1;
          ACTIVITY;
          ASSIGN,ATRIB(14)=-2,1;
          ACTIVITY;
          GOON,1;
          ACTIVITY,,ATRIB(16).EQ.1;
          ACTIVITY,,ATRIB(16).EQ.2,ZADW;
          GOON,1;
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```
        ACTIVITY,,ATRIB(9).EQ.1,ITT;
        ACTIVITY,,ATRIB(9).EQ.0,LRT;
ZADW    GOON,1;
        ACTIVITY,,ATRIB(9).EQ.1,ITT2;
        ACTIVITY,,ATRIB(9).EQ.0,LRT2;
ZADY    ASSIGN,ATRIB(9)=1,1;
        ACTIVITY,,,ZADX;
;
SST2    GOON,1;
        ACTIVITY,TRIAG(0.1333,0.1666,0.2);
ZAEK    BATCH,12/7,4,,LAST/10,11,12,13,14,ALL(8),1;
        ACTIVITY;
ASSIGN,XX(35)=ARRAY(8,ATRIB(4)),XX(36)=ARRAY(9,ATRIB(4)),XX(37)=ARRAY(10,
        ATRIB(4)),1;
        ACTIVITY,TRIAG(XX(35),XX(36),XX(37));
        COLCT,INT(6),DOWN_T_2,,1;
        ACTIVITY;
        UNBATCH,8,1;
        ACTIVITY,,ATRIB(10).EQ.-1;
        ACTIVITY,,ATRIB(10).EQ.-2,ZAEA;
        ACTIVITY,,ATRIB(11).EQ.-1,ZAEB;
        ACTIVITY,,ATRIB(11).EQ.-2,ZAEC;
        ACTIVITY,,ATRIB(12).EQ.-1,ZAED;
        ACTIVITY,,ATRIB(12).EQ.-2,ZAEE;
        ACTIVITY,,ATRIB(13).EQ.-1,ZAEF;
        ACTIVITY,,ATRIB(13).EQ.-2,ZAEG;
        ACTIVITY,,ATRIB(14).EQ.-1,ZAEH;
        ACTIVITY,,ATRIB(14).EQ.-2,ZAEI;
        ACTIVITY,,ATRIB(17).EQ.1,ZAEJ;
        FREE,CREW2_2,1;
        ACTIVITY;
ZADZ    BATCH,2/7,3,,,,1;
        ACTIVITY,,,SM62;
ZAEA    FREE,CREW2_0,1;
        ACTIVITY,,,ZADZ;
ZAEB    FREE,SE1_2,1;
        ACTIVITY,,,ZADZ;
ZAEC    FREE,SE1_0,1;
        ACTIVITY,,,ZADZ;
ZAED    FREE,SE2_2,1;
        ACTIVITY,,,ZADZ;
ZAEE    FREE,SE2_0,1;
        ACTIVITY,,,ZADZ;
ZAEF    FREE,TE1_2,1;
        ACTIVITY,,,ZADZ;
ZAEG    FREE,TE1_0,1;
        ACTIVITY,,,ZADZ;
ZAEH    FREE,TE2_2,1;
        ACTIVITY,,,ZADZ;
ZAEI    FREE,TE2_0,1;
        ACTIVITY,,,ZADZ;
ZAEJ    TERMINATE;
;
LST2    GOON,1;
        ACTIVITY,TRIAG(0.5,0.6666,0.8333),,ZAEK;
;
SRT2    GOON,1;
        ACTIVITY,TRIAG(0.1333,0.1666,0.2),,ZAEK;
;
LRT2    GOON,1;
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         ACTIVITY,TRIAG(0.5,0.6666,0.8333),,ZAEK;
;
ITT2     GOON,1;
         ACTIVITY,TRIAG(0.25,0.3333,0.5833),,ZAEK;
;
SM51     GOON,1;
         ACTIVITY,,ATRIB(19).EQ.1;
         ACTIVITY,,ATRIB(19).EQ.2,ZAEL;
         ASSIGN,XX(46)=XX(46)+1,ATRIB(21)=ARRAY(21,XX(46)),ATRIB(22)=ARRAY(22,XX(
         46)),ATRIB(23)=ARRAY(23,XX(46)),1;
         ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM61;
ZAEL     ASSIGN,XX(47)=XX(47)+1,ATRIB(21)=ARRAY(21,XX(47)),ATRIB(22)=ARRAY(22,XX(
         47)),ATRIB(23)=ARRAY(23,XX(47)),1;
         ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM61;
;
SM61     BATCH,6/18,2,,,,1;
         ACTIVITY;
         GOON,1;
         ACTIVITY,,ATRIB(19).EQ.1;
         ACTIVITY,,ATRIB(19).EQ.2,ZAEM;
         ASSIGN,XX(48)=XX(48)+1,ATRIB(21)=ARRAY(24,XX(48)),ATRIB(22)=ARRAY(25,XX(
         48)),ATRIB(23)=ARRAY(26,XX(48)),1;
         ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM71;
ZAEM     ASSIGN,XX(49)=XX(49)+1,ATRIB(21)=ARRAY(24,XX(49)),ATRIB(22)=ARRAY(25,XX(
         49)),ATRIB(23)=ARRAY(26,XX(49)),1;
         ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM71;
;
S1       ASSIGN,ATRIB(20)=TNOW,1;
         ACTIVITY;
         ASSIGN,XX(55)=XX(55)+1,1;
         ACTIVITY,,XX(55).LE.6;
         ACTIVITY,,XX(55).GT.6,ZAER;
ZAEQ     QUEUE(1),,,;
         ACTIVITY(12),TRIAG(0.08333,0.11667,.16667);
         GOON,3;
         ACTIVITY;
         ACTIVITY,,,SM2;
         ACTIVITY,,,SM3;
SM1      GOON,1;
         ACTIVITY,,ATRIB(19).EQ.1;
         ACTIVITY,,ATRIB(19).EQ.2,ZAEN;
         ASSIGN,XX(40)=XX(40)+1,ATRIB(21)=ARRAY(12,XX(40)),ATRIB(22)=ARRAY(13,XX(
         40)),ATRIB(23)=ARRAY(14,XX(40)),1;
         ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM51;
ZAEN     ASSIGN,XX(41)=XX(41)+1,ATRIB(21)=ARRAY(12,XX(41)),ATRIB(22)=ARRAY(13,XX(
         41)),ATRIB(23)=ARRAY(14,XX(41)),1;
         ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM51;
SM2      GOON,1;
         ACTIVITY,,ATRIB(19).EQ.1;
         ACTIVITY,,ATRIB(19).EQ.2,ZAEO;
         ASSIGN,XX(42)=XX(42)+1,ATRIB(21)=ARRAY(15,XX(42)),ATRIB(22)=ARRAY(16,XX(
         42)),ATRIB(23)=ARRAY(17,XX(42)),1;
         ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX1;
```

```
ZAEO
ASSIGN,XX(43)=XX(43)+1,ATRIB(21)=ARRAY(15,XX(43)),ATRIB(22)=ARRAY(16,XX(
        43)),ATRIB(23)=ARRAY(17,XX(43)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX1;
SM3     GOON,1;
        ACTIVITY,,ATRIB(19).EQ.1;
        ACTIVITY,,ATRIB(19).EQ.2,ZAEP;

ASSIGN,XX(44)=XX(44)+1,ATRIB(21)=ARRAY(18,XX(44)),ATRIB(22)=ARRAY(19,XX(
        44)),ATRIB(23)=ARRAY(20,XX(44)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX1;
ZAEP
ASSIGN,XX(45)=XX(45)+1,ATRIB(21)=ARRAY(18,XX(45)),ATRIB(22)=ARRAY(19,XX(
        45)),ATRIB(23)=ARRAY(20,XX(45)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX1;
ZAER
ASSIGN,XX(40)=0,XX(41)=0,XX(42)=0,XX(43)=0,XX(44)=0,XX(45)=0,XX(46)=0,XX(
        47)=0,XX(48)=0,XX(49)=0,XX(50)=0,XX(51)=0,XX(55)=1,1;
        ACTIVITY,,,ZAEQ;
;
SM71    GOON,1;
        ACTIVITY,,ATRIB(19).EQ.1;
        ACTIVITY,,ATRIB(19).EQ.2,ZAES;

ASSIGN,XX(50)=XX(50)+1,ATRIB(21)=ARRAY(27,XX(50)),ATRIB(22)=ARRAY(28,XX(
        50)),ATRIB(23)=ARRAY(29,XX(50)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM81;
ZAES
ASSIGN,XX(51)=XX(51)+1,ATRIB(21)=ARRAY(27,XX(51)),ATRIB(22)=ARRAY(28,XX(
        51)),ATRIB(23)=ARRAY(29,XX(51)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM81;
;
UMX1    BATCH,6/18,2,,,,1;
        ACTIVITY,,,F;
;
SM81    GOON,1;
        ACTIVITY,TRIAG(0.08333,0.11666,0.1666);
        ASSIGN,XX(56)=XX(56)+1,1;
        ACTIVITY,,,DIST;
;
SM52    GOON,1;
        ACTIVITY,,ATRIB(19).EQ.1;
        ACTIVITY,,ATRIB(19).EQ.2,ZAET;

ASSIGN,XX(66)=XX(66)+1,ATRIB(21)=ARRAY(21,XX(66)),ATRIB(22)=ARRAY(22,XX(
        66)),ATRIB(23)=ARRAY(23,XX(66)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM62;
ZAET
ASSIGN,XX(67)=XX(67)+1,ATRIB(21)=ARRAY(21,XX(67)),ATRIB(22)=ARRAY(22,XX(
        67)),ATRIB(23)=ARRAY(23,XX(67)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM62;
;
SM62    BATCH,6/18,2,,,,1;
        ACTIVITY;
        GOON,1;
        ACTIVITY,,ATRIB(19).EQ.1;
        ACTIVITY,,ATRIB(19).EQ.2,ZAEU;

ASSIGN,XX(68)=XX(68)+1,ATRIB(21)=ARRAY(24,XX(68)),ATRIB(22)=ARRAY(25,XX(
        68)),ATRIB(23)=ARRAY(26,XX(68)),1;
        ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM72;
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```
     ZAEU
ASSIGN,XX(69)=XX(69)+1,ATRIB(21)=ARRAY(24,XX(69)),ATRIB(22)=ARRAY(25,XX(
           69)),ATRIB(23)=ARRAY(26,XX(69)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM72;
     ;
     S2    ASSIGN,ATRIB(20)=TNOW,1;
           ACTIVITY;
           ASSIGN,XX(75)=XX(75)+1,1;
           ACTIVITY,,XX(75).LE.6;
           ACTIVITY,,XX(75).GT.6,ZAEZ;
     ZAEY  QUEUE(17),,,;
           ACTIVITY(12),TRIAG(0.08333,0.11667,.16667);
           GOON,3;
           ACTIVITY;
           ACTIVITY,,,ZAOJ;
           ACTIVITY,,,ZAOK;
     ZAOI  GOON,1;
           ACTIVITY,,ATRIB(19).EQ.1;
           ACTIVITY,,ATRIB(19).EQ.2,ZAEV;

ASSIGN,XX(60)=XX(60)+1,ATRIB(21)=ARRAY(12,XX(60)),ATRIB(22)=ARRAY(13,XX(
           60)),ATRIB(23)=ARRAY(14,XX(60)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM52;
     ZAEV
ASSIGN,XX(61)=XX(61)+1,ATRIB(21)=ARRAY(12,XX(61)),ATRIB(22)=ARRAY(13,XX(
           61)),ATRIB(23)=ARRAY(14,XX(61)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM52;
     ZAOJ  GOON,1;
           ACTIVITY,,ATRIB(19).EQ.1;
           ACTIVITY,,ATRIB(19).EQ.2,ZAEW;

ASSIGN,XX(62)=XX(62)+1,ATRIB(21)=ARRAY(15,XX(62)),ATRIB(22)=ARRAY(16,XX(
           62)),ATRIB(23)=ARRAY(17,XX(62)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX2;
     ZAEW
ASSIGN,XX(63)=XX(63)+1,ATRIB(21)=ARRAY(15,XX(63)),ATRIB(22)=ARRAY(16,XX(
           63)),ATRIB(23)=ARRAY(17,XX(63)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX2;
     ZAOK  GOON,1;
           ACTIVITY,,ATRIB(19).EQ.1;
           ACTIVITY,,ATRIB(19).EQ.2,ZAEX;

ASSIGN,XX(64)=XX(64)+1,ATRIB(21)=ARRAY(18,XX(64)),ATRIB(22)=ARRAY(19,XX(
           64)),ATRIB(23)=ARRAY(20,XX(64)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX2;
     ZAEX
ASSIGN,XX(65)=XX(65)+1,ATRIB(21)=ARRAY(18,XX(65)),ATRIB(22)=ARRAY(19,XX(
           65)),ATRIB(23)=ARRAY(20,XX(65)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,UMX2;
     ZAEZ
ASSIGN,XX(60)=0,XX(61)=0,XX(62)=0,XX(63)=0,XX(64)=0,XX(65)=0,XX(66)=0,XX(
           67)=0,XX(68)=0,XX(69)=0,XX(70)=0,XX(71)=0,XX(75)=1,1;
           ACTIVITY,,,ZAEY;
     ;
     UMX2  BATCH,6/18,2,,,,1;
           ACTIVITY,,,F2;
     ;
     SM72  GOON,1;
           ACTIVITY,,ATRIB(19).EQ.1;
           ACTIVITY,,ATRIB(19).EQ.2,ZAFA;
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ASSIGN,XX(70)=XX(70)+1,ATRIB(21)=ARRAY(27,XX(70)),ATRIB(22)=ARRAY(28,XX(
           70)),ATRIB(23)=ARRAY(29,XX(70)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM82;
     ZAFA
ASSIGN,XX(71)=XX(71)+1,ATRIB(21)=ARRAY(27,XX(71)),ATRIB(22)=ARRAY(28,XX(
           71)),ATRIB(23)=ARRAY(29,XX(71)),1;
           ACTIVITY,TRIAG(ATRIB(21),ATRIB(22),ATRIB(23)),,SM82;
     ;
     SM82  GOON,1;
           ACTIVITY,TRIAG(0.08333,0.11666,0.1666);
           ASSIGN,XX(76)=XX(76)+1,1;
           ACTIVITY,,,DIST;
            END;
      FIN;
```

ARRAY STORAGE REPORT

DIMENSION OF NSET/QSET(NNSET):	150000
WORDS ALLOCATED TO FILING SYSTEM:	13500
WORDS ALLOCATED TO VARIABLES:	11690
WORDS AVAILABLE FOR PLOTS/TABLES:	124810

EXECUTION WILL BE ATTEMPTED

APPENDIX O

Comparison of MRET Model Results with SLAM II Simulation

Table O-1. Mean and Standard Deviation of Down Time at Site Level

RL	Pr. of obtaining resources from site P (STA)	Discrete Event Simulation (SLAM II)		Model (MRET)					
				Mean			St. Dev.		
		Mean	St Dev.	Result	Error	Error [%]	Result	Error	Error [%]
3	0.99973	45.91	11.99	46.926	1.016	2.21%	12.01	0.02	0.17%
3	0.9966	45.83	12.38	46.971	1.141	2.49%	12.042	-0.338	-2.73%
3	0.966	45.39	12.84	47.431	2.041	4.50%	12.441	-0.399	-3.11%
3	0.9211	46.15	13.33	48.158	2.008	4.35%	13.026	-0.304	-2.28%
3	0.7787	49.65	13.62	50.922	1.272	2.56%	15.141	1.521	11.17%
2	0.996	46.16	12.3	46.98	0.82	1.78%	12.045	-0.255	-2.07%
2	0.97	46.65	12.93	47.301	0.651	1.40%	12.032	-0.898	-6.95%
2	0.87	48.25	14.8	49.087	0.837	1.73%	13.607	-1.193	-8.06%
2	0.78	49.61	16.27	51.297	1.687	3.40%	15.351	-0.919	-5.65%
2	0.569	53.02	20.42	61.771	8.751	16.51%	25.038	4.618	22.62%
1	0.96	49.18	18.4	47.64	-1.54	-3.13%	12.491	-5.909	-32.11%
1	0.87	54.48	23.77	49.5	-4.98	-9.14%	13.74	-10.03	-42.20%
1	0.66	65.5	38.5	57.4	-8.1	-12.37%	20.79	-17.71	-46.00%
1	0.52	74.18	48.11	68.507	-5.673	-7.65%	27.061	-21.049	-43.75%
1	0.3	93.28	66.65	105.7	12.42	13.31%	26.174	-40.476	-60.73%

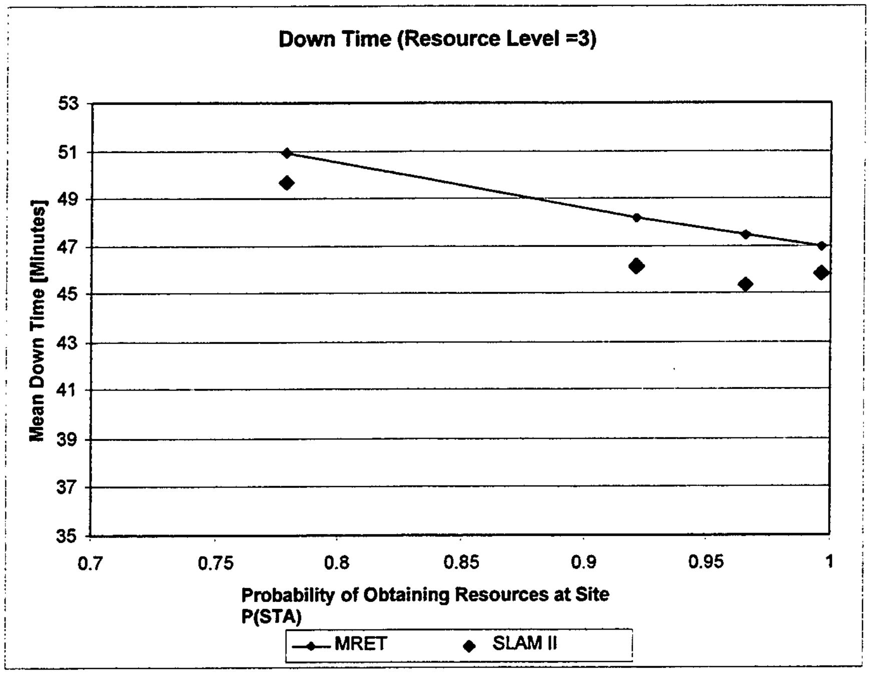

Figure O-1. Mean Down Time at Resource Level 3

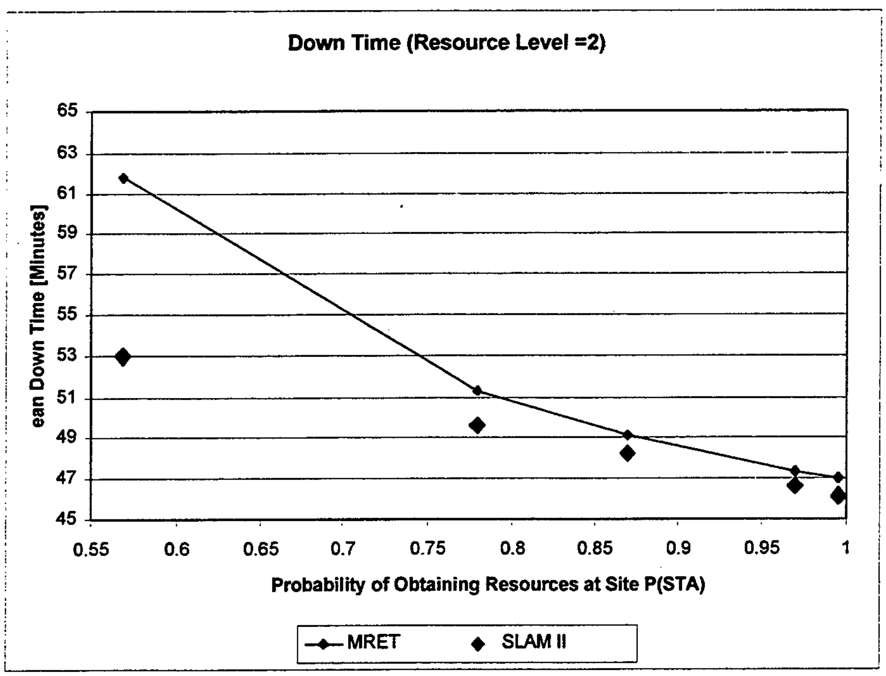

Figure O-2. Mean Down Time at Resource Level 2

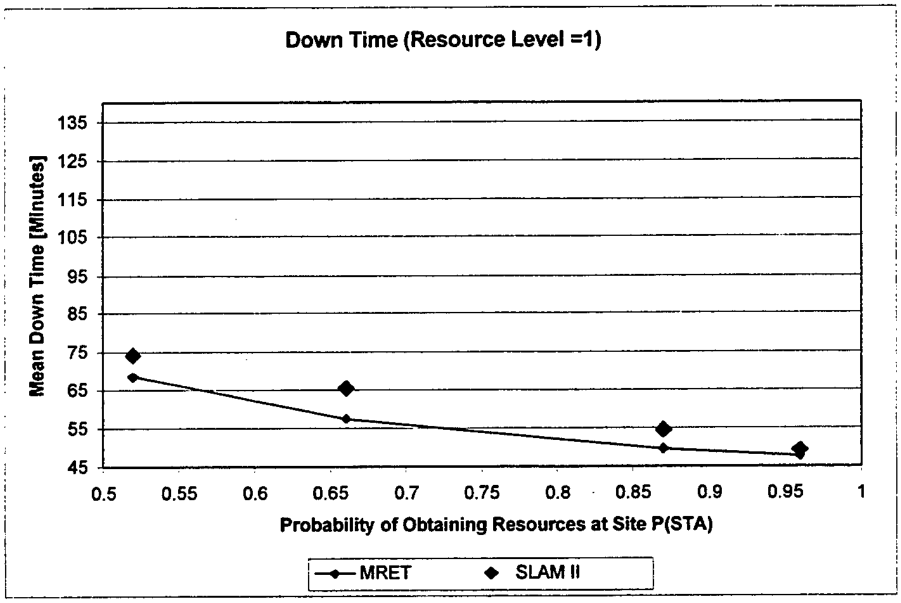

Figure O-3. Mean Down Time at Resource Level 1

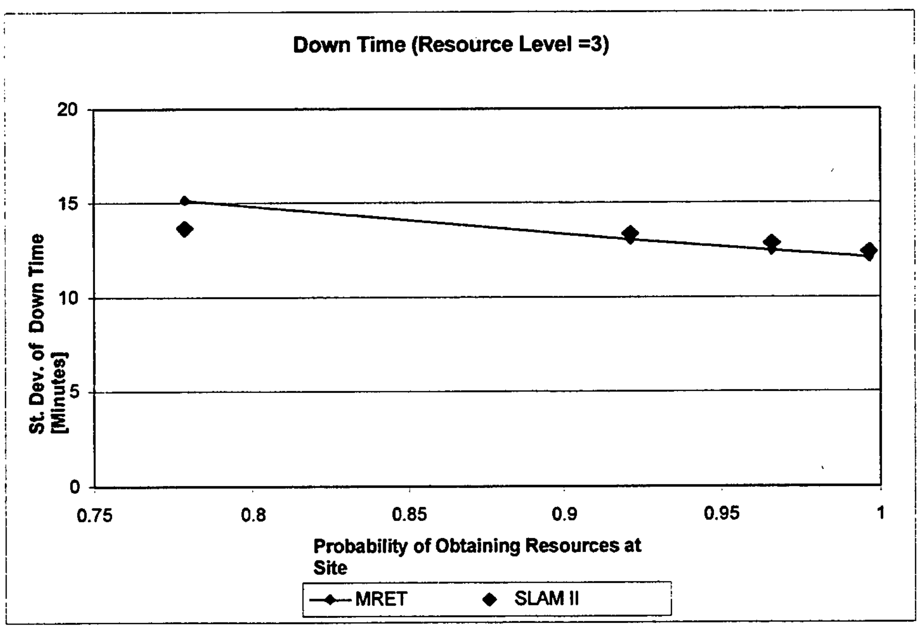

Figure O-4. Standard Deviation of Down Time at Resource Level 3

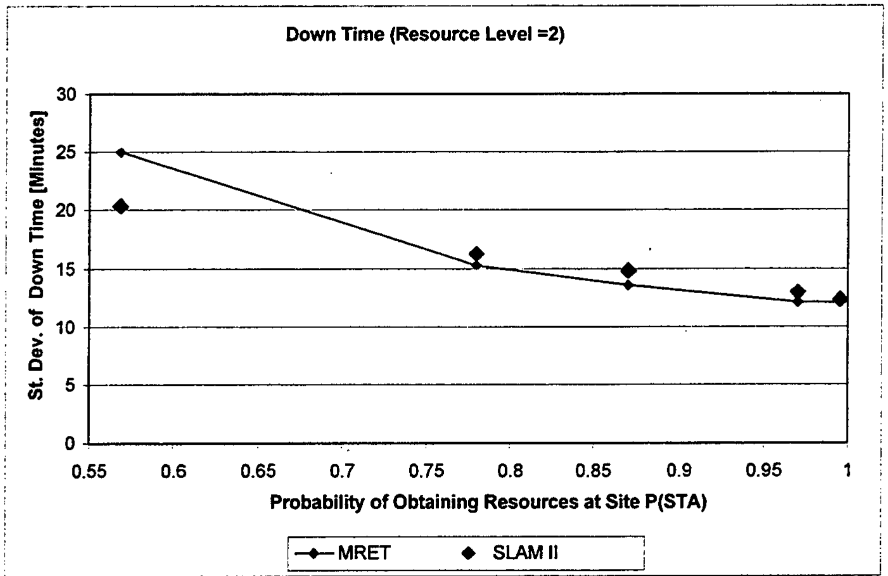

Figure O-5. Standard Deviation of Down Time at Resource Level 2

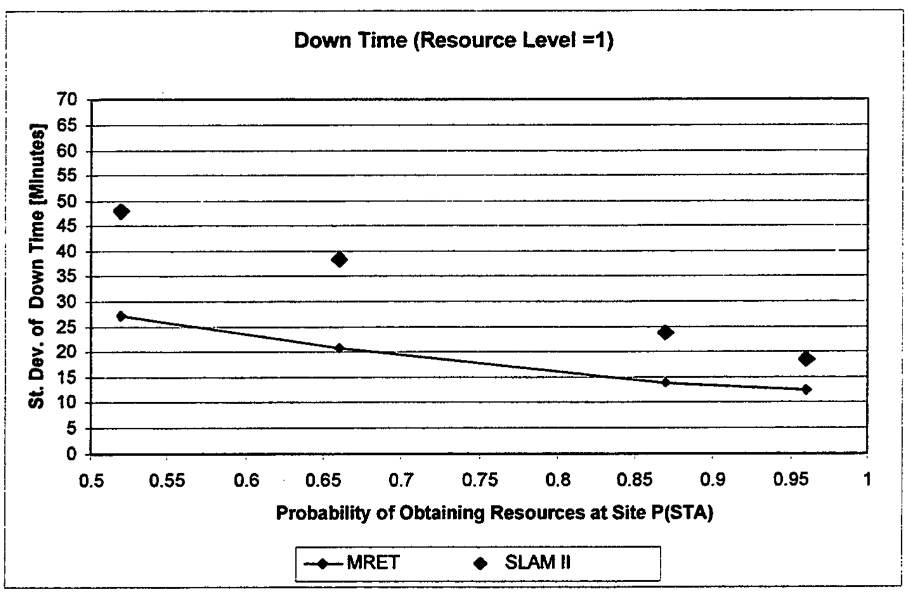

Figure O-6. Standard Deviation of Down Time at Resource Level 1

Table O-2. Mean and Standard Deviation of Recovery Time

RL	Pr. of obtaining resources from site P (STA)	Discrete Event Simulation (SLAM II)		Model (MRET)					
				Mean			St. Dev.		
		Mean	St Dev.	Result	Error	Error [%]	Result	Error	Error [%]
3	0.99973	45.91	11.99	46.926	1.016	2.21%	12.01	0.02	0.17%
3	0.9966	45.83	12.38	46.971	1.141	2.49%	12.042	-0.338	-2.73%
3	0.966	45.39	12.84	47.431	2.041	4.50%	12.441	-0.399	-3.11%
3	0.9211	46.15	13.33	48.158	2.008	4.35%	13.026	-0.304	-2.28%
3	0.7787	49.65	13.62	50.922	1.272	2.56%	15.141	1.521	11.17%
2	0.996	46.16	12.3	46.98	0.82	1.78%	12.045	-0.255	-2.07%
2	0.97	46.65	12.93	47.301	0.651	1.40%	12.032	-0.898	-6.95%
2	0.87	48.25	14.8	49.087	0.837	1.73%	13.607	-1.193	-8.06%
2	0.78	49.61	16.27	51.297	1.687	3.40%	15.351	-0.919	-5.65%
2	0.569	53.02	20.42	61.771	8.751	16.51%	25.038	4.618	22.62%
1	0.96	49.18	18.4	47.64	-1.54	-3.13%	12.491	-5.909	-32.11%
1	0.87	54.48	23.77	49.5	-4.98	-9.14%	13.74	-10.03	-42.20%
1	0.66	65.5	38.5	57.4	-8.1	-12.37%	20.79	-17.71	-46.00%
1	0.52	74.18	48.11	68.507	-5.673	-7.65%	27.061	-21.049	-43.75%
1	0.3	93.28	66.65	105.7	12.42	13.31%	26.174	-40.476	-60.73%

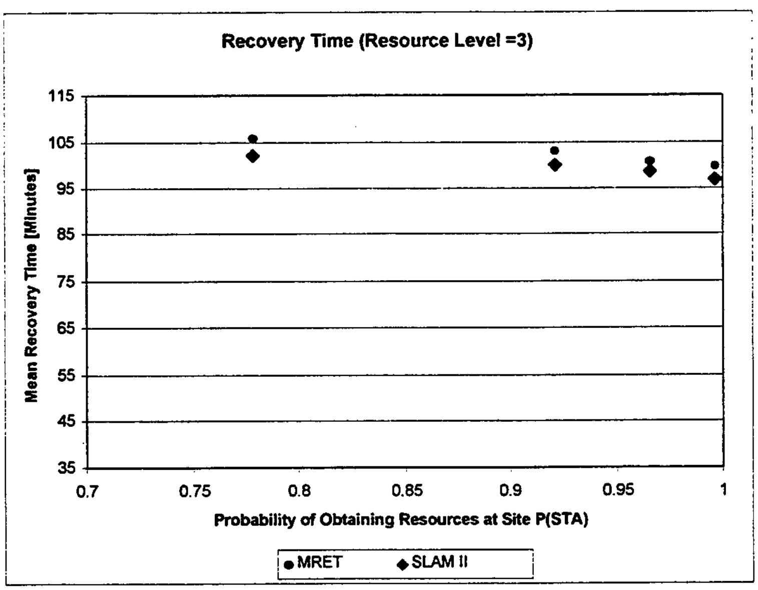

Figure O-7. Mean Recovery Time at Resource Level 3

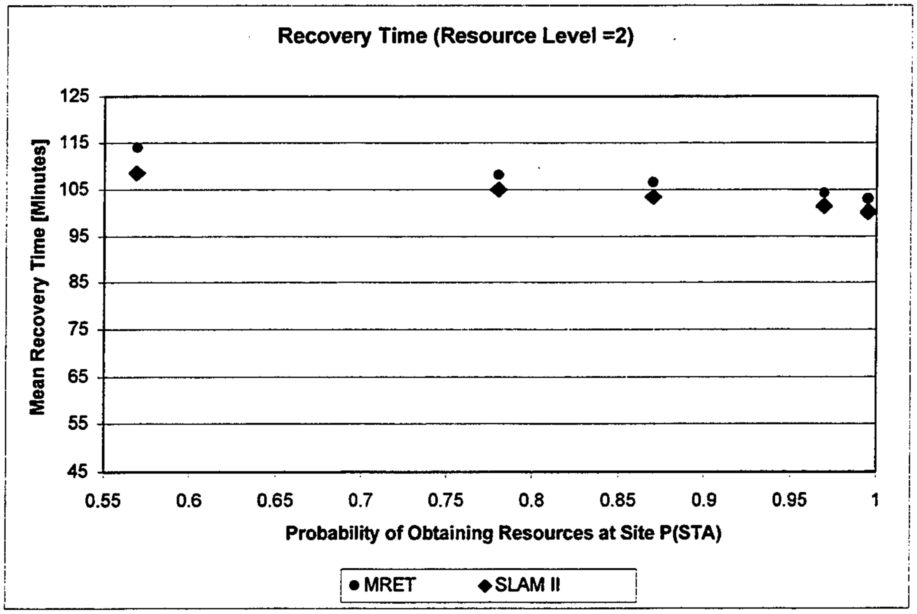

Figure O-8. Mean Recovery Time at Resource Level 2

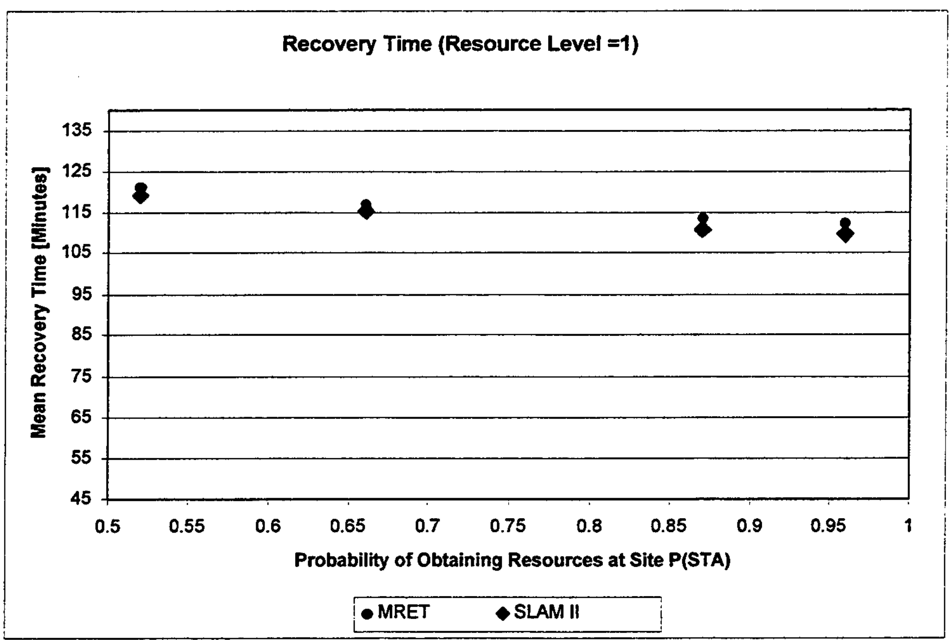

Figure O-9. Mean Recovery Time at Resource Level 1

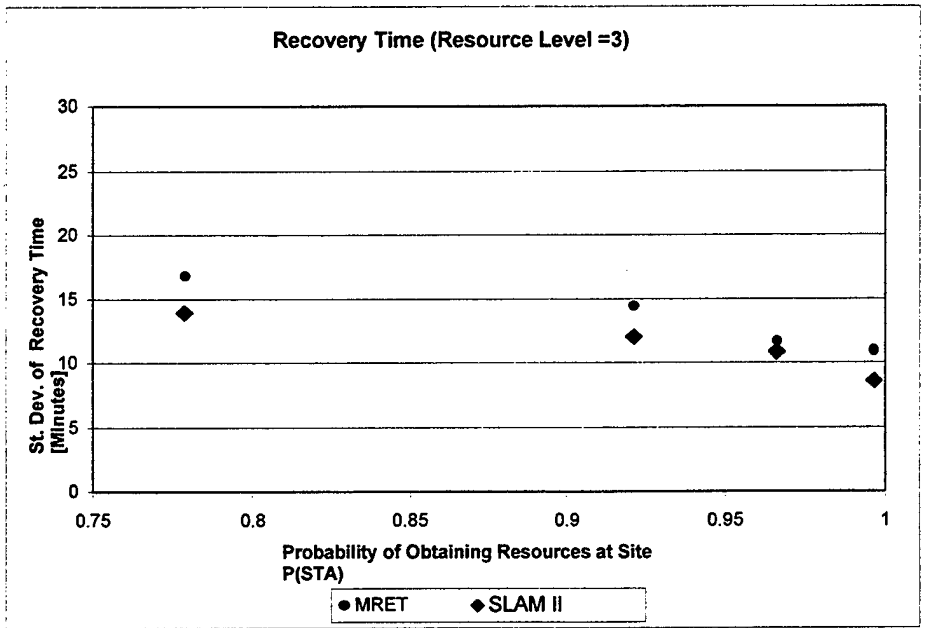

Figure O-10. Standard Deviation of Recovery Time at Resource Level 3

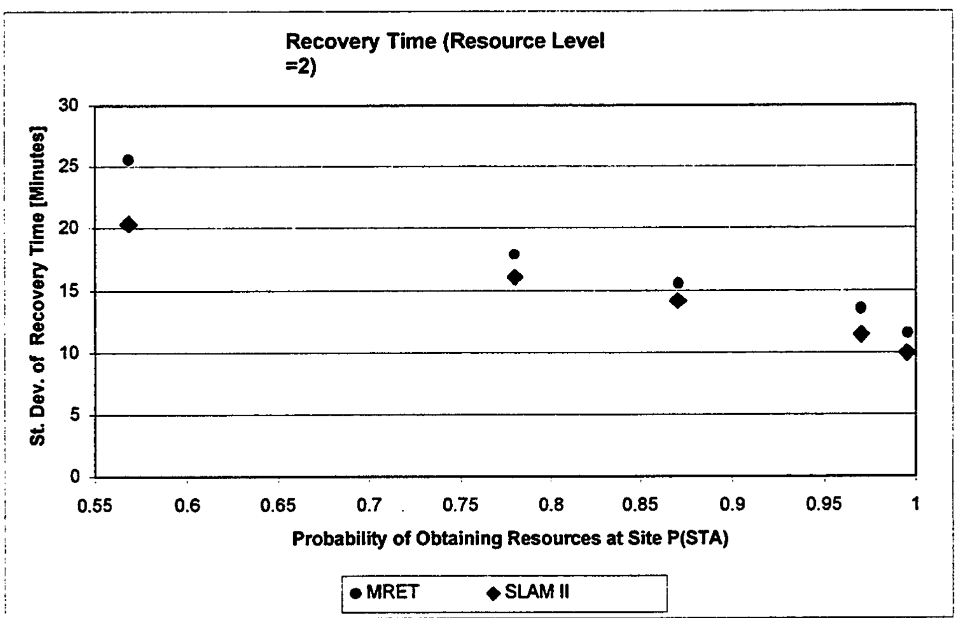

Figure O-11. Standard Deviation of Recovery Time at Resource Level 2

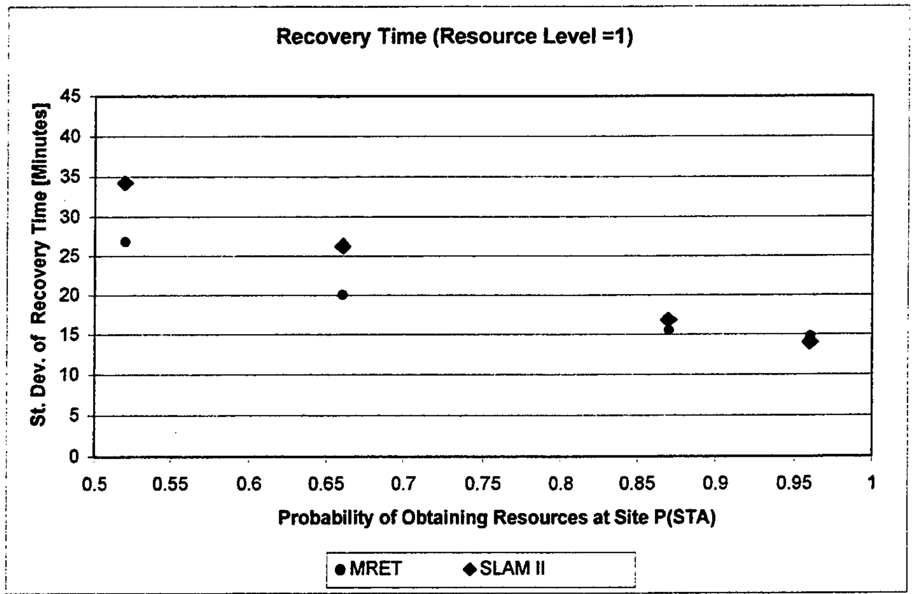

Figure O-12. Standard Deviation of Recovery Time at Resource Level 1

Table O-3. Number of Aircraft Recovered in a Given Interval at Resource Level 3

	RL = 3					
	P (STA)= 0.996			P(STA)= 0.778		
Interval [minutes]	SLAM	MRET	Error [%]	SLAM	MRET	Error [%]
90	1.669067	1.34	-19.72%	1.227733	1.09	-11.22%
100	9.573267	8.69	-9.23%	7.111933	6.22	-12.54%
110	11.60033	10.85	-6.47%	9.047867	8.18	-9.59%
120	11.86133	11.7	-1.36%	10.9386	9.8	-10.41%
130	11.921	11.84	-0.68%	11.28453	10.88	-3.58%
140	11.998	11.94	-0.48%	11.9922	11.41	-4.85%
150	11.998	12	0.02%	11.9922	11.78	-1.77%
160	11.998	12	0.02%	11.9922	11.85	-1.19%
170	11.998	12	0.02%	11.9922	11.92	-0.60%
180	11.998	12	0.02%	11.9922	11.98	-0.10%

Table O-4. Number of Aircraft Recovered in a Given Interval at Resource Level 2

	RL = 2					
	P (STA) =	0.95		P(STA)=	0.569	
Interval [Minutes]	SLAM	Model	Error [%]	SLAM	Model	Error [%]
90	1.1466	1.12	-2.32%	0.83974	0.78	-7.11%
100	7.021933	5.87	-16.40%	5.590467	4.54	-18.79%
110	9.928067	8.95	-9.85%	8.0784	6.89	-14.71%
120	10.9946	11.02	0.23%	10.0136	8.61	-14.02%
130	11.8874	11.78	-0.90%	10.96913	9.55	-12.94%
140	11.9976	11.94	-0.48%	11.90833	10.11	-15.10%
150	11.9976	11.98	-0.15%	11.90833	10.71	-10.06%
160	11.9976	11.98	-0.15%	11.90833	11.02	-7.46%
170	11.9976	11.99	-0.06%	11.90833	11.47	-3.68%
180	11.9976	11.99	-0.06%	11.90833	11.67	-2.00%

Table O-5. Number of Aircraft Recovered in a Given Interval at Resource Level 1

	RL = 1					
	P(STA)= 0.32			P(STA) = 0.778		
Interval	SLAM	Model	Error [%]	SLAM	Model	Error [%]
90	0.364	0.36	-1.19%	0.6306	0.57	-9.61%
100	2.779	2.15	-22.63%	3.599467	2.99	-16.93%
110	5.045	4.05	-19.72%	6.206267	5.43	-12.51%
120	7.313	6.09	-16.72%	8.347533	7.91	-5.24%
130	9.457	7.56	-20.06%	11.39353	10.82	-5.03%
140	10.983	8.06	-26.61%	11.98353	11.56	-3.53%
150	10.983	8.33	-24.16%	11.98353	11.86	-1.03%
160	10.983	8.66	-21.15%	11.98353	11.94	-0.36%
170	10.983	9.13	-16.87%	11.98353	12	0.14%
180	10.983	9.71	-11.59%	11.98353	12	0.14%

APPENDIX P

List of Acronyms and Abbreviations

λ_i	Failure rate of failure mode i
AAF	Argentine Air Force
ADE	Adaptive
AD	Aircraft design
ARR	Alternative required resources
AS	Alert schedule
BAD	Base attack damage
BD	Battle damage
CC	Cannibalization criterion
CL	Combat losses
COM	Complete
CO	Consumable
CR	Computer resources
CT	Cross training
CTA_i	Transit time from central facility for type-A resources (failure mode i)
CTB	Transit time from central facility for type-B resources
CV	Coefficient of variation (σ/μ)
CV_{AR}	Maximum CV of type-A resources (AND-node approximation formula)
D	Dispersion

DTA_i	Transit time from other maintenance site for type-A resources for failure mode i (after a delay due to utilization in site of origin)
E	Environmental
EA	Enemy action
EC	Easy to control
EV	Evolutionary
EW	Easy to communicate with (model characteristic)
FA	Facilities
FC	Failure criticality
f_i	Relative frequency of occurrence of a random variable Z_i
F_i	Frequency of utilization of a type-A resource i
FM	Facility maintenance
FP	Flying program
k	Number of random events
LUD	Logistics Unit of Deployment
m	Number of maintenance sites
MA	Manpower
MBA	Masters in Business Administration
MCC	Mission cancellation criterion
MP	Maintenance policy
MPO	Mission priority
MRET	Maintenance Resources Evaluation Technique

MRP	Material Requirements Planning
MWC	Minimum weather condition
n	Number of critical failure modes
ND	Number of type-A resources (AND node approximation formula)
NF_i	Number of failures that require type-B resource i
OP	Operational policy
p	Number of aircraft at site
p_i	Probability of occurrence of a random variable Z_i
$P(CDTA_i)$	Probability of obtaining type-A resource i from central facility or other maintenance site
$P(CDTA_i)_k$	Probability of obtaining type-A resource i from central facility or other maintenance, for use at site k
$P(CTA_i)$	Probability of transit time from central facility for type-A resources for failure mode i
P(CTB)	Probability of transit time from central facility for type-B resources
$P(DTA_i)$	Probability of Transit time from other maintenance site for type-A resources for failure mode i (after a delay due to use at site of origin)
$P(STA_i)$	Probability of transit time from site for type-A resources for failure mode i
P(STB)	Probability of transit time from site for type-B resources
$P(Z_i)$	Probability of a generic random variable Z_i
PHS	Packaging, handling and storage

PIS	Preventive inspection schedule
POL	Petroleum and oil
PRM	Probability of retaining munitions/TRAP
RA	Resource availability
RAC_i	Number of type-A resources i required at the central facility
RA_i	Number of type-A resources i required at site
RE	Reparable
RM	Average transit time for type-A resources
RO	Robust
RP	Reliability parameters
RPR	Resupply procedure
RR	Required resources
RSL	Required skills level
RTD	Repair time distributions
S	Substitutability
SAC_i	Quantity of type-A resources i available at the central facility
SA_i	Quantity of type-A resources i available at site
SE	Support equipment
SEPS	Support equipment periodic servicing
SEUM	Support equipment unscheduled maintenance
SL	Secondary logistics
SM	Transit time mean for type-B resource (AND-node approximation

	formula)
SP	Supply policy
SS_i	Quantity of type-B resources *i* stored at site
STA_i	Transit time from site for type-A resources for failure mode *i*
STB	Transit time from site for type-B resources
$\overline{T}$	Mean of a joint random variable *T*
TE	Test Equipment
T_i	Time resultant of a combination of random distributions
t_j	Time flown by aircraft *j* in the previous mission
TL	Tasks level
TM	Technical manuals
TO	Task organization
TP	Task priority
TRAP	Tanks, racks, adapters, and pylons
TT	Transit Time
$\overline{TT}_i$	Mean transit time for failure mode *i*
UDT	Unscheduled Down Time
UDT_i	Unscheduled down time failure for mode *i*
$\overline{UDT}_{A/C}$	Mean unscheduled down time at aircraft level
$\overline{UDT}_i$	Mean unscheduled down time failure for mode *i*
$\overline{UDT}_{A/C}\ j$	Mean unscheduled down time at aircraft level for aircraft *j*

$\overline{UDT}_{Site}$	Mean unscheduled down time at maintenance site level
$\overline{UTT}_i$	Mean unscheduled maintenance task time for failure mode *i*
UN	Understandable (model characteristic)
UTT	Unscheduled maintenance task time
VAR(T)	Variance of time resultant of a combination of random distributions
$VAR(TT_i)$	Variance of transit time for failure mode *i*
$VAR(UDT_{A/C\,j})$	Variance of unscheduled down time for aircraft *j*
$VAR(UDT_{A/C})$	Variance of unscheduled down time at aircraft level
$VAR(UDT_i)$	Variance of unscheduled down time failure for mode *i*
$VAR(UDT_{Site})$	Variance of unscheduled down time at site level
$VAR(UTT_i)$	Variance of unscheduled maintenance task time for failure mode *i*
$VAR(Z_i)$	Variance of the values of a random variable Z_i
WDTT	Weather dependent transit times
WSP	Work shift policy
Z_i	Generic random variable
$\overline{Z_i}$	Mean value of a random variable Z_i

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VITA

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REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 074-0188

1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	March 1999	Master's Thesis

4. TITLE AND SUBTITLE
MAINTENANCE RESOURCES EVALUATION TECHNIQUE

5. FUNDING NUMBERS

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAMES(S) AND ADDRESS(S)
Air Force Institute of Technology
2750 P Street
WPAFB OH 45433-7765

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GLM/LAL/99M-1

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited.

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 Words)*

The Argentine Air Force (AAF) has undertaken the task of reviewing its logistics doctrine with the aim of supporting its mission on the basis of better-designed resource structures. The adequate sizing of logistics support is essential to obtain the desired military capability, while optimizing resource use. A decision support tool tailored to the AAF environment is needed to size that logistics support. This research developed a mathematical logistics model to evaluate the mean number of aircraft that can be restored in a given time interval between consecutive sorties, for a given maintenance resources mix and base physical geometry. This *maintenance resources evaluation technique* (MRET) uses an analytical methodology to estimate the expected parameters of the unscheduled down time distribution. These parameters are then used in a Monte Carlo simulation of the user-defined network of scheduled and unscheduled maintenance tasks necessary to launch aircraft sorties. The MRET, although not externally validated, performed successfully during the verification process conducted in this research. Programmed on a spreadsheet, the MRET combines a high response speed with a moderately detailed description of the operations and logistics scenario. These characteristics make the model suitable for the AAF environment.

14. SUBJECT TERMS
Planning- Logistics Planning- Air logistics Support- Deployment- Aircraft Maintenance- Decision Aids- Operations Research- Mathematical Models- Computarized Simulation- Network Flows.

15. NUMBER OF PAGES
254

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	UL

AFIT Control Number AFIT/GLM/LAL/99M-1

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